The Royal School Series.

ELEMENTARY MECHANICS;

OR,

FIRST LESSONS IN NATURAL PHILOSOPHY.

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ELEMENTARY MECHANICS.

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1. Introduction.—Let us consider what is meant by the word *force*, and what are the nature and character of the various forces at work around us, of which we often speak collectively under the name of the "forces of nature."

Day by day we see these forces at work, acting in various ways, and producing many and different results; but they very rarely excite our curiosity, for we have grown accustomed to them from seeing them so often. A storm excites our wonder, and we are curious to know more about that wonderful and mighty force which causes the vivid lightning and the deafening thunder. But how many of us think, even for a moment, about the ever-acting and far more important force which causes all substances to fall towards the ground, and which enables our bodies and all things around them to maintain their place upon the surface of the Earth?

This force of *gravitation* acts so constantly and so unchangingly, always producing the same unvarying results, that we do not recognize anything wonderful in it; and it is only by looking very closely into the results which this force produces, and by thinking long and deeply about them, that we are at last enabled to recognize how wonderful and beautiful even the commonest of such occurrences really is.

2. Examples of Force.—If we take a piece of paper, set it upon edge against some object, as a book, and then pull it by means of a piece of thread attached to it, we notice that the paper falls. To pull the paper down we had to bring into use a power—the power of the muscles of the arm; and this power, carried along by the thread, caused the paper to fall. Or we may give the paper a push, and again it falls. This time we also use the power of our muscles, but in a different way. But we can cause the paper to fall by means of a very different power. Let us take a piece of sealing-wax, and, having well dried and warmed it, rub it with a piece of warm dry flannel or fur, and bring it within an inch or two of the paper. Now, although nothing touches the paper, we see it move towards the sealing-wax and fall. In the first case we pulled the paper over by means of the power of our muscles, which was transmitted by the string; in the next, the sealing-wax must have exercised a power to cause the paper to fall. Now, this power to set matter in motion, whether exerted by the hand or by the wax, is an instance of what we mean by the word *force.*

But power or force may be used for other purposes than moving a piece of paper. When a cannon is fired, the gunpowder with which it is loaded exerts force to propel the cannon-ball; and the target of iron against which the cannon-ball strikes must exert force to stop it. So also a boy playing cricket exerts force in striking the cricket-ball with his bat, causing it to fly swiftly across the field; and the boy who catches the ball exerts force in stopping it. Let us suppose, however, that the cricket-ball were a very large and very heavy one: the boy with the bat might try to move it, but fail; yet he would have exerted *force* in *trying* to move it; and were such a ball made to move, the other boy would expend force in *trying* to stop it, although he again might fail.

3. Definition of Force.—Thus we see that *force is that which moves or tries to move a body, or which changes or tries to change the motion of a body.*

4. Kinds of Motion.—We have seen that force frequently produces motion, and always tends to do so. We must now pause for a moment in order that we may learn something about motion. When a cannon is fired, we know that the gunpowder exerts a force which compels the cannon-ball to fly from the cannon, and to continue in motion until it comes to rest again perhaps a mile from the cannon. Here the cannon-ball *as a whole* moves a distance of one mile. Again, a locomotive engine may start from London, and at the end of about three hours may have arrived at Birmingham. Here again we notice that the *whole body* of the engine moves from one place to another. Motion of this kind we speak of as *motion of the body as a whole.*

5. Molecular Motion.—Let us now take the cannon-ball of which we have already spoken, and place it on a large fire. After a time it will become white hot, and will glow with heat. The body *as a whole* is perfectly still; it remains where we placed it on the fire. But is there any motion at all there? Yes, we think there is. We suppose that all bodies in the world, and the cannon-ball amongst them, are made up of an immense number of tiny pieces, too small to be seen, called *molecules.* When we place the cannon-ball on the fire, we think that these molecules are made to move by the heat—to swing backwards and forwards, as it were; and that the more we heat the ball the faster we make the molecules move, so that when the ball is white hot each molecule moves backwards and forwards with immense quickness. Thus, although the ball *as a whole* is perfectly at rest, every little molecule in it is swinging to and fro with almost inconceivable rapidity. This kind of motion we call *motion of the molecules of a body.* Thus we have two kinds of motion:—(1.) Motion of the body as a whole; (2.) Motion of the molecules of a body, or molecular motion. Now, whether the piece of matter be large or small—whether it be a *body* or a *molecule*—it will never move of itself. If it be moving, something must have acted on it to set it in motion, and the power which produces that motion is called a *force.*

6. Distinction between Matter and Force.—When we look around us, we see an immense number of different substances. Even within the four walls of a room we can count, perhaps, twenty or thirty distinct things, or even more. These substances are of different kinds. Some we can see, as wood, iron, glass; others we can only feel, as air; others, again, we can both see and smell, as oranges or musk; and others still we can taste. They all affect some one or more of our senses. If these substances are examined with the aid of a delicate balance, it will be found in addition that they all have *weight*. Now, all substances which can affect our senses, or which have weight, are spoken of under the general name of *matter*.

If an iron nail or a needle be placed on a piece of cork, and made to float on the surface of water in a basin, and a magnet is then brought near, the iron will be drawn towards the magnet. To produce this result the magnet must have exerted force. But the force cannot be seen, nor can it be detected by the aid of any of our senses. Since matter is said to be anything that affects our senses, and since force does *not* affect our senses, force cannot be a kind of matter. Or let an iron ball be carefully weighed, and afterwards raised to a red heat in a fire; then let it be weighed a second time, and it will be found to weigh exactly as much as at first. Since the iron weighs no more when hot than when cold, even when tested by the most delicate balance, it is clear that heat has no weight, and therefore cannot be matter. Thus we say that *force is not matter, but is that which acts upon matter.*

7. How Forces become known to us.—It is clear that force itself cannot be perceived by the aid of our senses; but force acting upon matter produces certain *effects*, and it is these effects that are recognized. Then from our observations conclusions are drawn as to the nature of the force which has produced these effects. Thus we cannot see, or feel, or weigh the force called magnetism; but we can see the magnet draw the iron nail towards it. We therefore feel sure that there must be some power or force existing in the magnet, and to this force we give the name of Magnetism.

II.—CLASSIFICATION OF FORCES.

8. The Forces of Nature—9. The Physical Forces—10. The Force of Gravity—11. The Force of Cohesion—12. The Force of Sound—13. The Force of Light—14. The Force of Heat—15. The Force of Magnetism—16. The Force of Electricity—17. Chemical Force—18. Muscular Force.

8. The Forces of Nature.—By the "forces of nature" we mean all those powers that are at work in the world, and which, by their action on matter, have made the world what it is. They may be divided into two classes: I. Physical Forces; II. Chemical Force.

9. The Physical Forces.—The physical forces are usually considered to be seven in number—namely, gravity, cohesion, sound, light, heat, magnetism, and electricity. We shall consider them in the above order.

10. The Force of Gravity.—If a ball is placed on a table and made to roll towards the edge, when it reaches the side of the table it will fall to the floor. Why should it fall? If no force acted on the ball, it would remain suspended in the air; but as it moves toward the ground, we conclude that some force is pulling it downward, and to that force the name of Gravity is given. If the ball were taken to twice the height, or to any still greater elevation, we know that it would fall in a similar way. Thus it is clear that the force of gravity can *act at a distance.* If the ball were examined after its fall, no change would be found to have taken place in the matter of which it was composed; it would retain in all probability its old shape, and if it were made of india-rubber, for instance, this substance would be found to have undergone no change. The force of gravity, therefore, not only acts at a distance, but also *produces no change in the substance* on which it acts. These two facts will be found to be characteristic of all the physical forces; and if a new force were to be discovered to-morrow which had these two properties, it would be classed at once among the physical forces.

11. **The Force of Cohesion.**—All the substances or bodies which form the world are believed to be each of them composed of an infinite number of very minute pieces called molecules. These molecules are too small to be seen, even with a microscope, and cannot be broken or divided by any physical means. The molecules of solid bodies are not free to move, but are held together, each in its own place, by a force to which the name of Cohesion has been given. If the molecules be separated from one another by too great a distance, as when the body is cut with a knife, cohesion cannot act, and the parts of the body fall asunder. In this respect cohesion differs somewhat from the other physical forces, since it can act only over the very small distances which separate molecules. But cohesion produces no change

in the *matter* of the body; for whether the matter of solid water (ice), in which cohesion is strong, or liquid water, in which cohesion is weak, or gaseous water (steam), in which cohesion is absent, be examined, it will be found to be always alike in its composition, always made of the two elements oxygen and hydrogen—always water.

12. The Force of Sound.—When a body is struck, a sound is generally produced. If such a body as a bell be struck and then carefully watched, it will be seen to vibrate—that is, its parts will move to and fro; and if the hand be placed upon it, the vibrations may be felt. These vibrations are taken up by the air and carried away by it on all sides, in a manner very similar to that in which waves spread away on all sides of a stone dropped into water. When these vibrations of the air (or sound-waves) reach our ears they produce the sensation we call sound.

13. The Force of Light.—Light, like sound, is caused by a vibratory or to-and-fro movement of the molecules of the body which is producing the light. When a body emits rays of light, it is supposed that its molecules are vibrating with enormous rapidity, and that these vibrations are carried away in all directions by a very thin gaseous substance or fluid called the ether. This ether is supposed to be extremely thin, or rare, and to be spread through all space and all matter. It is believed to fill the enormous space which exists between the Earth and the sun, moon, and other heavenly bodies, thus enabling their light to travel over the millions of miles which lie between them and us. We cannot *prove* the existence of this ether, but it is very convenient to suppose that such a substance exists.

14. The Force of Heat.—Very closely connected with the force of light is another force termed Heat. Heat is produced by a motion of the molecules of a body very similar to that which produces light. The molecules of all bodies are supposed to be in a state of motion. When this motion is slow, the body is said to be cold; and it is supposed that as the motion of the molecules becomes quicker so the body becomes hotter. Heat may be produced in many ways. If a button be rubbed smartly on a piece of wood, its molecules are set in motion, and it soon becomes too hot to be touched by the naked hand. Heat is also produced in all cases of burning; but whether produced in this or in any other way, heat always consists of a motion of the molecules of the heated body.

15. The Force of Magnetism.—When a common horse-shoe magnet is brought near a small piece of iron—an iron key, for instance—the iron moves toward the magnet; and if they are allowed to touch, the iron may be lifted up by the magnet. In order that the key may be so lifted, the magnet must exert a certain power or force, and this power which enables the magnet to lift the iron is called Magnetism. Even before the magnet touches the iron, the iron may be seen to move under the influence of the magnet. If the iron be afterwards examined, it will be found to be quite unchanged by the action of the magnetic force. This clearly indicates that magnetism, in common with the other forces we have named, is a physical force, since it can act at a distance and without changing the properties of the matter it acts upon.

16. The Force of Electricity.—By electricity we mean a power by which, for example, certain substances can attract, or draw towards themselves, light bodies. This electric power or force may be produced by various means, as by friction or rubbing, by chemical action, and in several other ways. If a piece of well-dried glass be rubbed with dry silk and brought near some small pieces of paper, they will be seen to jump up towards the glass. The same effect may be obtained by the aid of a piece of sealing-wax which has been rubbed with a hot dry flannel. The force of electricity is known to be very closely related to the force of magnetism.

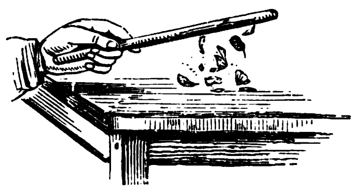

FIG. 1.
Rubbed Glass Rod and Bits of Paper.

17. Chemical Force.—Having examined some of the physical forces, it is now necessary to consider the second division of the forces of nature—namely, the *Chemical Force.* As an example of this force, let us take an ounce of loaf-sugar and grind it to a powder; mix with it two ounces of a white substance called chlorate of potash, similarly powdered. If the mixture is left alone, it will remain unchanged for almost any length of time. But let the end of a glass rod, moistened with strong sulphuric acid (oil of vitriol), be now brought near a portion of the mixture. As long as the acid does not *touch* the mixture no change takes place. It may be brought within the smallest distance short of actual contact and nothing happens. But let the acid *touch* the powder, and the latter at once bursts into a brilliant violet flame, giving off a dense white smoke, and in a moment or so nothing remains but a few blackened cinders. Here, then, is an action totally different from any we have hitherto mentioned. It was necessary, before any effect was produced, that the substances should be actually *touching;* and the result of the action was a substance *totally different* from those we had before. The force which produced this great change is called the Chemical Force.

As another illustration of chemical force, let a small quantity of bichloride of mercury be dissolved in water in a glass, and let a little iodide of potassium be treated in the same way in another glass. The two substances may be held as close to each other as possible, but no change will be visible. Let the one liquid, however, be poured into the other, and instantly a beautiful salmon-coloured substance will be formed, quite different in every respect from the two colourless liquids from which it was derived. This second instance of the action of chemical force clearly points out the facts, that this force, unlike the physical forces, *cannot act at a distance;* and that when it does act, it completely *changes the nature* of the substances upon which it acts.

18. Muscular Force.—There is one force which is perhaps the most familiar to us of all the forces. This is the force possessed by the masses of red flesh called muscles, by means of which we move our bones, lift weights, etc. The way in which a muscle exerts force is by *contracting.* When, for example, we bend our arm, it is easy to feel the muscle in the upper part of the arm becoming short and thick.

FIG. 2.

a, The Muscle which Bends the Arm.
b, The Muscle which Straightens it.

We must notice, however, that the muscles can only exert force when the animal to which they belong is *alive.* For this reason the muscular force is also called the *vital force,* or the force possessed by living beings.

III.—THE FORCE OF GRAVITY.

19. Division of the Study of Forces.—It would not be possible to include, in the study of Mechanics, an account of all the forces of nature. The study of the modes of action of the chemical force constitutes the science of chemistry. Sound, light and heat, electricity and magnetism, are also considered as distinct sciences. The way in which the muscular force of our bodies is produced and maintained belongs to the science of animal physiology. Cohesion we spoke of in the first part of this book. There remains therefore only the force of gravity, which we must now examine more closely and endeavour to understand.

20. Why Bodies fall towards the Earth.—If any portion of matter, as a stone, be not supported—that is, be not held up in any way—it will be seen to move towards the Earth. This is a fact which comes under our notice every day, and in whatever part of the world we may be it remains true. We have learned that that which produces motion is a force, therefore some force must have acted upon the stone to cause it to move toward the Earth; and as in all parts of the world things fall in the same direction—that is, toward the Earth—it is only natural that we should conclude that the force which causes the stone to fall resides in or is possessed by the Earth. To this force the name of *Gravity* has been given; a word derived from the Latin word *gravis*, which means *heavy;* and gravity is said to be "that force which causes all bodies to fall to the Earth when not supported." This is plainly the case with solids and liquids. We have only to take away their support, and they immediately fall. So also do heavy gases, such as carbonic acid gas, which may be poured out of any vessel containing it just like so much water (Fig. 3). But light gases, such as hydrogen, do not seem to obey this law. If a small balloon be filled with hydrogen, it rises to the top of the room. But this is only because it is pushed upward by

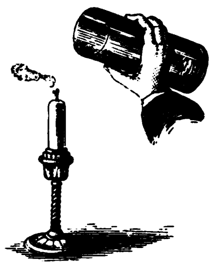

FIG. 3.
Pouring Carbonic Acid Gas. That it falls downward is shown by the candle-flame being extinguished.

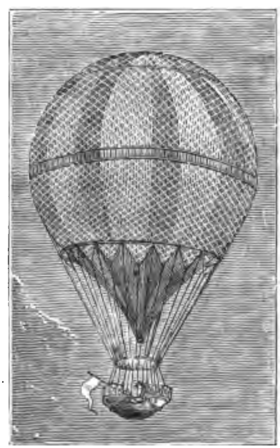

FIG. 4.
Balloon filled with Hydrogen Gas rising through the Air.

the heavier air; just as a cork is forced up to the surface of any water in which it may be immersed, by the water (which is heavier than the cork) getting underneath it. If the balloon filled with hydrogen is placed where there is nothing to press it up or to support it, as in a vacuum or completely empty space, then the hydrogen will fall towards the Earth just as the heavier carbonic acid gas did in the open air.

21. The Force of Gravity acts at all Distances.—We can set no bounds to the action of gravity. If a body be taken up in a balloon miles above the Earth, we know that gravity is still acting on it, and we have only to set the body free to see it fall back to the Earth. Gravity, however, acts over distances far greater than any that can be reached by man. By this force the planets are made to circle round the Sun, and the Moon to revolve round the Earth. When used in this *universal* sense, meaning the attraction of the heavenly bodies for one another, the term *gravitation* is generally used; while we speak of the force of *gravity* when we mean only the attraction of the Earth for bodies near its surface.

22. The first Law of Gravitation.—We owe the greater part of our knowledge concerning the laws which regulate the force of gravity to Sir Isaac Newton (born 1642; died 1727). It is said of this great man that being one day in an orchard he saw an apple fall from a tree, and immediately asked himself *why* and *how* the apple fell. Led by this apparently small circumstance, he began a series of experiments which ended in his discovery of the laws according to which gravity acts. These laws are two in number. The first law states that "*Every body attracts every other body with a force proportionate to its mass.*" From this we learn that the attraction of gravitation is not only an attraction of one heavenly body for another, or of the Earth for bodies near it, but that *every body in the universe attracts every other body.* From this it is clear that when two balls are suspended a few inches apart, each attracts the other, and tends to approach it. So, also, when the Earth attracts a ball and causes it to fall, the ball also pulls the Earth and makes it rise. If this be so, how is it that we only see the ball fall, and do not see the Earth rise? In order to understand this clearly, we must know what is meant by the word *mass* as used in the law just stated. By "mass" is meant *the quantity of matter which any body contains.* Thus, if we take two ivory balls of the same size, weight, and kind, they will each contain the same quantity of matter, or have the same mass, and the two together will have twice the mass of one of them. These balls, if hung up at a distance of one foot apart, will each attract the other with a certain force. Let one of them be made twice as heavy as the other, and the power of attraction of this ball will be doubled. Let it be made four times as heavy, and its power of attraction will be fourfold that of the lighter ball. Now imagine one ball to be increased to the size of a mountain, and its power to attract will be increased in the same proportion. The attractive force of a little ball is too small to be measured, but the force of gravity possessed by a mountain may be made clearly perceptible.

23. Experimental Proof of the first Law of Gravitation.—In the year 1774, Dr. Maskelyne suspended a small ball near the mountain Schiehallion, in Perthshire, and he found that the ball was plainly attracted towards the mountain.

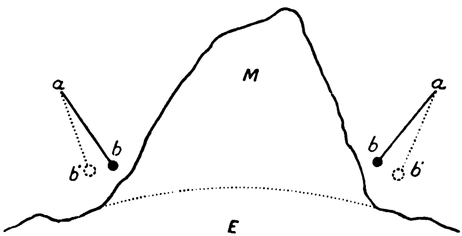

FIG. 5.—The Schiehallion Experiment.

The ball, *b*, is suspended by the fine thread, *a b*. If the mountain, M, were removed, the ball would hang vertically, in the direction *a b′*. But the matter of which the mountain is composed attracts the ball, and draws it a little towards the mountain. The same thing occurs on whichever side of the mountain the experiment is performed; the suspended ball is always drawn a little towards the mountain.

Now we can understand why the Earth cannot be seen to move towards a falling ball. The Earth's mass is so many million times greater than the mass of the ball, that the Earth moves towards the ball through a distance too small to be measured or seen. So, also, it is clear why the Earth circles round the Sun, and not the Sun round the Earth: it is because the mass of the Sun is much greater than the mass of the Earth. For the same reason the Moon goes round the Earth, and not the Earth round the Moon. The mass of the Sun is no less than three hundred thousand times greater than the mass of the Earth; and the mass of the Earth is forty-nine times greater than the mass of the Moon.

24. Second Law of Gravitation.—Not only does the force of gravitation vary with the mass of bodies, but it also changes according to the *distance* by which they are separated from one another. If the two ivory balls before mentioned be placed near each other, they will each attract the other with a certain force; if the distance is increased the attraction will become less; while if the distance is lessened the attraction of the balls for one another will increase. Newton's second law of gravitation gives the relation between the distance and the attracting force. It says: "*All bodies attract each other inversely as the square of the distance between them.*" We will first explain the meaning of the two words *inversely* and *square*. To *invert* a thing is to place it upside down. The number 3 will be unaltered if we write it thus, $\frac{3}{1}$, but $\frac{3}{1}$ inversely becomes $\frac{1}{3}$ (one-third); so 4 or $\frac{4}{1}$ inversely is $\frac{1}{4}$; and 9 or $\frac{9}{1}$ inversely is $\frac{1}{9}$. The number 1, being represented thus, $\frac{1}{1}$, will be unchanged if taken inversely.

The word *square*, as used in this law, is easily explained. A number is squared when it is multiplied by itself once. Thus 3 squared, or the square of 3, is $3 \times 3 = 9$; and 9 squared will be 9×9—that is, 81; and so on.

25. Illustrations of the second Law of Gravitation.—Let two balls be suspended one foot apart. They will attract each other with a certain force which we will represent by the number 1. Now let the balls be removed to a distance of two feet apart. How great then is the attraction between them? It will be only *one-fourth* as great as at first. To prove this, let the respective distances be represented by the numbers 1 and 2. Now the attraction does not vary as the distance, but as the *square* of the distance; so that the numbers 1 and 2 must be squared, giving $1 \times 1 = 1$, and $2 \times 2 = 4$. But the attraction is not merely as the square of the distance, but *inversely* as the square of the distance between the two balls; therefore the numbers 1 and 4 must be inverted, becoming 1 and $\frac{1}{4}$. If, then, two bodies attract each other with a certain force when they are one foot apart, at double that distance the attraction is only one-fourth as great, at three times the distance one-ninth as great, at a distance of four feet the attraction is only one-sixteenth as great as at one foot; and so on. Since a body on the Earth's surface is 4,000 miles from the centre of the Earth, it is clear that if we could raise the body to a height of 4,000 miles *above* the surface, it would be attracted only one-quarter as strongly, at a height of 8,000 miles only one-ninth as strongly as on the surface; and so on. If the body weighed one pound at the surface, it would weigh only one-quarter pound at 4,000 miles high, and one-ninth pound at 8,000 miles; the weight being tested by a spring balance.

In order to obtain a perfectly clear idea of what is meant by this law of inverse squares, it will be necessary to work out numerous examples in the manner above indicated, and to endeavour to express correctly the answers in words.

Suppose the only pieces of matter in the whole universe were two raindrops, at a distance, say, of one million miles apart. Since each drop possesses the force of gravity, they would attract each other and would begin to move one towards the other. At first, as the distance between them is so great, the attraction would be very small, and they would move very slowly; but as that distance decreased, the attraction would increase, and they would move faster and faster, till at last they would meet midway, each having travelled exactly half a million miles.

26. Why Rain falls.—In exactly the same way a raindrop formed in the clouds attracts our Earth and is attracted by it. Each moves towards the other—the raindrop towards the Earth and the Earth towards the raindrop; but while the little ball—the raindrop—moves downwards, say, one mile, the great ball—the Earth—moves upwards only the smallest imaginable fraction of an inch. The consequence is that we can see the raindrop fall, but we cannot see the Earth rise to meet it.

IV.—EFFECTS OF THE FORCE OF GRAVITY.

27. Meaning of the Words "up" and "down."—When a body is dropped we say that it falls *down;* and in whatever part of the world we may be living we make use of the same expression. As our Earth is shaped like a ball, it is clear that in different places on its surface bodies falling towards the centre of the Earth must fall in different directions. Thus a ball dropped in England will move in a direction exactly opposite to that taken by a ball dropped in New Zealand, and a ball dropped at the equator will move in a direction nearly at right angles to both.

Let A B C D (Fig. 6) be four points above the surface of the Earth, from which stones are let fall, and let the circle represent the surface of the Earth; let *e m s o* be the points on the surface of the Earth on which the stones will fall when allowed to move. The four stones will move in the directions shown by the four arrows. The stone A moves in an opposite direction to the stone C; the stone B will move from right to left, while the stone D will move from left to right. The four movements are thus in four different directions; but if these directions be continued as indicated by the dotted lines, they will each pass through the centre of the Earth, which is represented by the letter X. Thus, when we make use of the word *down* we mean *toward the centre of the Earth;* and by the word *up* we mean in the opposite direction —namely, *away from the centre of the Earth.*

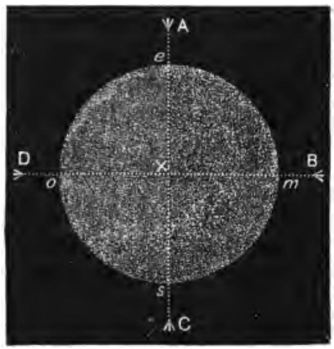

FIG. 6.
Bodies fall toward the centre of the Earth.

A straight line drawn from any point toward the centre of the Earth is called a vertical line, and a line drawn at right angles to this is called a horizontal line. All bodies, then, in all parts of the world, fall vertically. From this we see that the force of gravity acts as if it were seated at the Earth's centre, which is therefore called the *centre of gravity* of the Earth. Instead of saying that bodies fall toward the centre of the Earth, it will mean the same thing if we say that they fall toward the centre of gravity of the Earth, for this is situated at the centre of the Earth.

28. The Force of Gravity is the Cause of Weight.— When a body is supported, as when it is lying on a table, it appears at first sight as if gravity had no effect upon it. But if the body be placed on the hand, a certain pressure will be felt. This is caused by the force of gravity attracting the body, and endeavouring to make it move downward; in so doing it causes the body to press on the hand. This pressure is called the weight of the body. Weight, then, may be defined to be "*the downward pressure of any body caused by the attraction of gravity.*" We can now better understand why the attraction of the Earth bears the name of gravity; for the Latin word *gravis*, from which it is derived, means *heavy*, and the heaviness or weight of any body is due to the force of gravity.

In the fact that different bodies have different weights we have a good illustration of the law that gravity attracts bodies in proportion to their *mass*. Thus, if a solid piece of iron of a certain size be taken, it will be pulled down with a certain force; suppose the force to be equal to one pound. If a second piece of iron of exactly the same kind, but of twice the size, be taken, it will be pulled downward with twice the force; that is, with a force equal to two

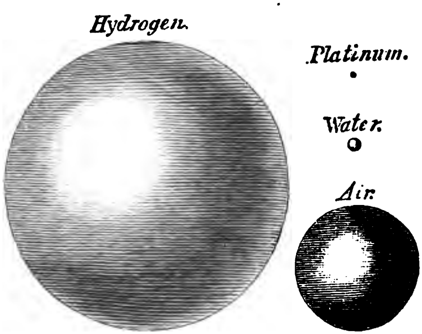

FIG. 7.—Volume and Mass.

pounds. A body with three times the mass will be attracted three times as strongly; and so on. A piece of platinum, whose volume is, say, one cubic inch, weighs three times as much as a piece of iron of the same volume, because it is attracted three times as strongly by the Earth; hence we say that the *mass* of the platinum is three times as great as the mass of the iron, and we believe that there is three times as much matter in it. In Fig. 7 we have represented the relative volume, or bulk, of *equal masses* of platinum, water, air, and hydrogen.

29. Centre of Gravity.—Bodies are composed of an immense number of tiny pieces or molecules. The force of gravity acts on each of these molecules, drawing it downwards, and not only on those on the outside of the body. Thus, if a ball of clay be taken, every molecule of that ball will be acted on by gravity; and the weight—that is, the force with which gravity pulls the piece of clay—will be unaltered, in whatever shape it may be moulded, so long as the number of molecules remains the same. Thus the clay may be flattened into a sheet, or moulded into a brick, or rolled into a rod, and yet its weight remains unaltered.

Now there is one point within all bodies at which their weight may be considered to be concentrated. This point is called "the centre of gravity" of the body; and if this point be supported, the whole body will be supported. Thus if a ruler be marked exactly in the middle and then suspended at that point, it will usually be found to balance. The centre of gravity of the ruler must therefore be situated at the middle of the ruler. We can understand this if we consider that on each side of the middle point the ruler is made up of an equal number of molecules which balance one another; and we might add equal weights to each end of the ruler without at all disturbing its balance, since they would neutralize each other.

30. Centre of Gravity of regular Bodies.—In the case of a body of regular shape it is a comparatively easy matter to find the position of its centre of gravity. It will only be necessary to find a point situated so as to have an equal quantity of matter on all sides, or, in other words, to find the middle point of the figure, and this will be the centre of gravity. In a ball or sphere, the centre of gravity is the centre of the sphere. In a cube, the centre of gravity is at the point which we may call the centre of the figure—namely, the point where straight lines joining opposite corners would cross. The same rule gives the centre of gravity of a body shaped like a brick, which may be called oblong bodies. The centre of gravity of a cylinder is midway between the centres of the circular ends. The centre of gravity of a circular piece of card-board or of a ring is the centre of the circle. In a piece of card-board of triangular shape the centre of gravity may be found by drawing lines from the middle points of two sides to the opposite angles: the point in which these lines cut one another is the centre of gravity of the triangle. The centre of gravity of a cone or pyramid is found by the following rule:—Join the point or apex of the cone or pyramid with the centre of the base, and measure off three-quarters of the length of this straight line from the apex. The point so obtained is the centre of gravity of the cone or pyramid.

31. Centre of Gravity of irregular Bodies.—In the case of bodies which have not a regular shape we cannot so easily determine, by calculation, the position of the centre of gravity. It can, however, be always determined by experiment, as follows:—Take any irregularly-shaped body, as a piece of card-board (A B C D, Fig. 8); make a hole in it with a brad-awl at A, and hang it up from this point by means of a piece of string. The string will of course hang vertically. Draw a line in this vertical direction across the card, as A C. Now suspend the card in a similar way from any other point in it, as B, and, as before, draw a vertical line, B D. The point E, where these lines cut, will be the centre of gravity of the body; and if the card be suspended from any other point, it will be found that the line drawn vertically downward from that point will always pass through the centre of gravity, E. If the end of the finger be placed under the centre of gravity, the card will be found to balance about that point; but if the finger be moved only an inch to the right or the left, the card will no longer balance. From this we see that if a body

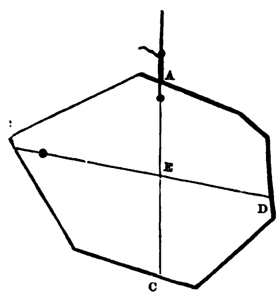

FIG. 8.—Centre of Gravity.

is to remain at rest it must have its centre of gravity supported; for if this be not done, the body must move in some direction or other until it finds a support for its centre of gravity.

32. The Centre of Gravity of any Body seeks to place itself in the lowest possible Position.—As gravity pulls all bodies toward the centre of the Earth, it is clear that they will come to rest with their centres of gravity as near to the centre of the Earth as possible. Thus if a weight be suspended by a string, it will remain at rest only when it is as low as it can get; and this will be when the string hangs straight up and down, or vertically. If the weight be now moved ever so short a distance to the one side or the other, its centre of gravity will be slightly raised; and when the body is set free it will return to its old position.

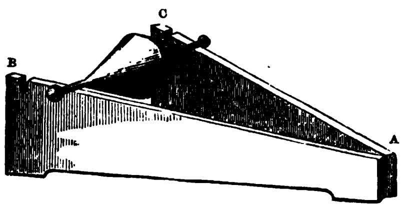

FIG. 9.—Double Cone rolling (apparently) up-hill.

Fig. 9 shows a roller shaped like a double cone resting on two inclined pieces of wood, which touch at A, but are wide apart at B and C. When this roller is set free at A, it begins at once to roll towards B C, although to do this it apparently rolls up-hill. If, however, the vertical height above the table of the centre of gravity of the roller be measured, first at A and then at B C, it will be found to be nearer the table at B C than at A; the reason being, that the conical shape of the roller allows its centre of gravity to move down more than the inclined pieces of wood raise it up. In the same way we may explain the action of the toy shown in Figs. 10 and 11. This toy, we might think, ought to remain lying on its side when we place it so (Fig. 10), but it does not;

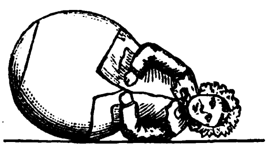

FIG. 10.

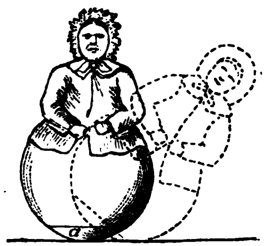

FIG. 11.

it always gets up again (Fig. 11). Now we may be perfectly sure that there is some arrangement by which the centre of gravity is in its lowest position when the image is standing upright. This is effected by putting a piece of lead inside the lower part of the image, as at *a*, Fig. 11.

33. Stable and unstable Equilibrium.—We have seen that if a body is to remain at rest in any given position, its centre of gravity must be supported. When the centre of gravity of a body is supported in such a way that the body remains at rest, it is said to be in equilibrium. It is usually pos-

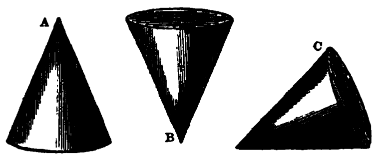

FIG. 12.
Three kinds of Equilibrium.

sible to support a body in more than one way. Thus a cone may be made to rest upon its base (Fig. 12, A). or upon its apex (Fig. 12, B), or upon its side (Fig. 12, C). In the first case (A) the centre of gravity is as low as it can be placed, and if the cone be slightly inclined to either side it will return again to its old position. In this position the cone is said to be in stable equilibrium. In the second case (B) not only would there be considerable trouble in getting the cone to balance on its point, but the slightest disturbance afterwards would cause it to fall. A body in this state is said to be in unstable equilibrium.

34. Neutral Equilibrium.—In the third case, however (C), when the cone rests upon its side, it may be moved, and will perhaps roll some distance, but will at last come to rest, still lying on its side. This condition is said to be one of neutral equilibrium. A ball placed upon a table is also in neutral equilibrium, for it will rest indifferently on any part of its surface; but if a hole be cut in one side of the ball, and a heavy substance, such as a piece of lead, be placed in the hole, then the ball will come to rest only when that point rests upon the table: the ball will then be in stable equilibrium, for the centre of gravity will be in its lowest possible position.

35. Illustrations of Equilibrium.—Carts loaded with heavy weights, as iron, can travel along an uneven road without being upset, while those with a load of equal weight but of lighter material, such as hay, are likely to be overturned on the same road. In the first case the centre of gravity of the load and cart is low;

but in the second case, owing to the bulky nature of the load, the centre of gravity is higher up, and the cart is in a state of unstable equilibrium (Fig. 13). So long as a vertical line drawn from the centre of gravity falls between the wheels, the weight is supported by the road; but if the road slopes so much as to cause this line to fall outside either wheel, the weight is unsupported, and the cart must topple over sideways. So, too, the centre of gravity is much higher when the crew of a small boat are on their feet, than when they are seated, and it requires very little force to upset the boat in the former case. That is why we so often read of accidents caused by persons standing up in small boats. In all cases the larger the base of any body and the lower its centre of gravity, the more stable will the equilibrium be; the smaller the base and the higher the centre of gravity, the more unstable is the equilibrium, and the more easily will the body be overturned.

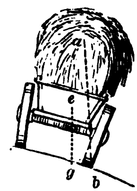

FIG. 13.

Hay-cart in a position of unstable equilibrium on sloping road. The centre of gravity (at *a*) is so situated that the vertical line, *a b*, falls just on the edge of one wheel. If the cart were loaded with iron its equilibrium would be much more stable, for its centre of gravity would be lower, as at *e*, and the vertical line *e g* would fall well between the two wheels.

There is a famous tower at Pisa, in Italy (see Fig. 14), which leans considerably to one side; but it is perfectly safe, for the vertical line connecting the centre of gravity of the tower with the centre of gravity of the Earth falls *within the base* of the tower.

V.—FALLING BODIES.

36. The Force of Gravity causes all Bodies to fall with the same Velocity—37. Resistance of the Air to falling Bodies—38. Experimental Illustrations—39. Bodies falling in a Vacuum—40. Uniform Velocity—41. Variable Velocity.

36. The Force of Gravity causes all Bodies to fall with the same Velocity.—When a body is supported in any way—as, for example, by the hand—the effect of the action of gravity on it is shown by the *weight* of the body; if the body is *not* supported, however, the effect produced by this force is perhaps clearer, for the body falls toward the centre of the Earth in a direction which we have learned to call vertical. Very wrong or uncertain ideas about falling bodies were held for a long time; and it was reserved for an Italian philosopher named Galileo to find out by observation and experiment, about the year 1590, the laws which govern the motion of falling bodies. His experiments consisted in watching the fall of various bodies dropped from the top of the Leaning Tower of Pisa in Italy (Fig. 14). One of the most important facts he learned was, that all bodies, when their motion is not interfered with in any way, fall equally fast.

Let us consider the case of two leaden balls, of the same size and weight, dropped side by side from a height of, say, twenty feet. Clearly they will move at the same rate and reach the ground at the same time. The balls may be brought so

FIG. 14.—Leaning Tower of Pisa.

near together that they will touch each other; still they will fall at the same pace. Let them be joined into one ball, and still no change will take place in their rate of motion. If instead of two balls we have a hundred, which are allowed to fall at the same time from the same height, these also will all reach the ground in exactly the same time; and if they were all rolled into one, this would produce no change whatever in their rate of motion. From this it is clear that all bodies, light and heavy, fall with the same velocity. Thus a two-pound weight and a one-pound weight let fall from the same height would reach the ground at the same time. This can easily be proved by experiment.

This may also be rendered clear in another way. We have seen that gravity attracts all bodies in proportion to their mass. Thus a ball of a certain mass will be attracted twice as strongly as another ball whose mass is only one-half as great. If these two balls be placed on a table, it will take just twice as much force to move the heavy one horizontally as it will to move the light one; and if we let a force of two pounds act on the large ball, while a force of one pound acts on the small ball, they will both roll at the same speed along the table. Now this is exactly the way in which gravity acts: the larger the mass of a body the greater is the force of gravity acting on it: hence all bodies, heavy and light, fall towards the centre of the Earth at the same rate, if they are dropped from the same place.

37. Resistance of the Air to falling Bodies.—But it may be said that if a gold coin and a piece of gold leaf be dropped at the same time, the coin will reach the ground long before the gold leaf. That is perfectly true; but the cause of the difference is the resistance which the air offers to the fall of all bodies. When a body falls it has to push aside the air lying between it and the Earth, just in the same way as a ball falling into a heap of sand has to push aside the particles of sand in order to move downward. Now, the coin being much the heavier, pushes aside the particles of air more easily than the very thin and light piece of gold leaf can, and therefore the coin falls the more rapidly of the two bodies.

38. Experimental Illustrations.—Take a piece of paper about two inches square, and a leaden bullet; let them fall together, and the bullet will quickly out-distance the paper, as it more easily overcomes the resistance of the air. Now roll the paper up into a ball, and let both the bodies fall a second time. The paper now, having much less surface, will not be so much hindered by the air, and both paper and bullet will reach the table at the same time. Again: cut out a circular piece of thin paper, slightly smaller than a penny, and drop the penny and the paper side by side: the paper will lag behind. Now place the paper on the top of the penny, and let them fall together. The penny, being underneath, prevents the paper from feeling the resistance of the air, and they both reach the table at the same time.

39. Bodies falling in a Vacuum.—But perhaps the most convincing proof is this:—If it be the air which resists the falling of bodies, then when we cause very heavy and very light bodies to fall in a place entirely empty of air, they should all fall with the same speed.

We can take all the air out of a vessel by means of an air-pump, and thus obtain what is called a vacuum. Place in the long glass tube (Fig. 15) a piece of gold leaf, a feather, a gold coin, and a bullet, and draw out all the air by an air-pump. Now quickly turn the tube upside down, and all the bodies, light and heavy, will be seen falling together to the bottom of the tube. As all bodies, light and heavy, fall with the same speed in a vacuum, it must be the resistance of the air which causes the difference in their rates of motion when they fall, some slowly and some rapidly, as we usually see them do in the air around us.

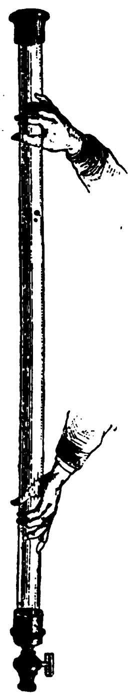

FIG. 15.
Falling Bodies.

40. Uniform Velocity.—It is now necessary that we should try to understand exactly the manner in which bodies fall. To do this, it will be necessary to use a few words, the meaning of which we will try to make clear beforehand.

The word *velocity*, as generally used, indicates great speed or quickness; but in mechanics the word simply means the speed or rate at which a body moves, whether that speed be great or small. Thus we may speak about a velocity of one mile per day or a velocity of sixty miles per minute with equal accuracy. There is, however, another point connected with this statement which it would be well to notice. When we say that a railway train moves with a velocity of sixty miles per hour, we understand that the train, moving along always at the same speed, travels sixty miles in an hour. So, too, if we say that a boy is walking at the rate of four miles per hour, we mean that if he were to continue moving along steadily for one hour at that rate, he would cover four miles. Motion of this kind is called *uniform* motion, and the velocity is called uniform velocity, because it is constant and unchanging. This kind of motion, too, is easily measured. Thus sound travels with the uniform velocity of 1,120 feet per second. If it be required to know how far a sound-wave will move in one minute, it is only necessary to multiply 1,120 by 60 (the number of seconds in one minute), and the answer is found to be 67,200 feet. Or, if a train has a uniform velocity of 30 miles per hour, we may want to know how far it will travel in one second. In 30 miles there are 158,400 feet; and in an hour there are 3,600 seconds. Divide 158,400 by 3,600. The answer is 44; so that we may say that the railway train moves with a velocity of 44 feet per second.

41. Variable Velocity.—Uniform motion is the simplest kind of motion, but we soon find that it is not the only kind. Thus, if an arrow be shot straight upward, the eye can easily see that as the arrow rises higher and higher it also gets slower and slower; and if a cricket ball be driven a long way over the ground by a stroke from a bat, it moves more and more slowly until it comes to rest. This is called variable motion; and bodies having this kind of motion are said to move with variable velocity.

VI.—FALLING BODIES.
(Continued.)

42. The Velocity of a falling Body is variable—43. Falling Bodies move with accelerated Velocity—44. Retarded Velocity—45. Velocity of falling Bodies—46. Amount of Acceleration of falling Bodies—47. Space passed over by a falling Body—48. Problems on falling Bodies.

42. The Velocity of a falling Body is variable.—It is much harder to catch a cricket ball that has been thrown to a great height than one that has been merely tossed up a few feet. Again, a boy may jump from a chair to the ground without inconvenience, but if he try to jump from the housetop he will probably break his legs. These facts show that the further a body falls the faster it falls. But why is it that falling bodies move with this changing or variable velocity? Let us suppose that a ball is dropped from any point. At the end of one second it will be moving with a certain velocity; this velocity has been given to it during that second by the attraction of gravity. During the next second, if it continues falling, it will gain as much velocity as it did during the first second, and this it will have *in addition* to what it had before; therefore, at the end of the *second* second it will have twice the velocity that it had at the end of one second. So also if it continues to fall during a *third* second, it will gain during this second as much velocity as it did during the first, in addition to what it had at the end of the *second* second; the falling ball will therefore have three times the velocity at the end of the *third* second that it had at the end of the *first* second.

43. Falling Bodies move with accelerated Velocity.—Any force which makes a body move faster and faster is called an accelerating (or hastening) force; and if it increases the velocity by the same amount every second, it is called a uniformly accelerating force. Gravity, then, as it makes bodies fall faster the further they fall, and as it always gives to them the same amount of extra velocity every second, is said to be a uniformly accelerating force.

44. Retarded Velocity.—But when any body, as a stone, is thrown upwards into the air, gravity, instead of adding to its velocity, takes away from it; and every second makes it move upward with less and less speed, until at length the stone is brought to rest in the air. If there were no force of gravity, the stone would go upward for ever; but gravity, constantly attracting it, makes the stone move more and more slowly, till at length it stops for an instant in the air, and is then compelled to return to the Earth. When the velocity decreases in this way, the motion of the body is said to be *retarded.*

45. Velocity of falling Bodies.—When any body, such as a ball, has been falling freely under the action of gravity for one second, it will be found to be moving at the rate of thirty-two feet per second. Of course the velocity has been gradually increasing, from the moment when the ball was dropped to the end of the second; and were the ball allowed to continue falling, the velocity would still increase up to the moment when the ball was stopped. As the velocity is continually changing, how can we speak of the velocity at any particular instant? When we say that at the end of the first second the ball moves at the rate of thirty-two feet per second, we mean that if the motion were to continue unchanged during the next second, the ball would move through a distance of thirty-two feet. Similarly we may see a train fly past a railway station, and we say that it is going sixty miles per hour. We may not see the train for more than half a minute, but what we mean is clear enough. It is not that the train will really travel sixty miles in the next hour, but that, *if it kept on at the same pace* for an hour, it would travel sixty miles.

46. Amount of Acceleration of falling Bodies.—If the falling ball be watched at the end of the *second* second, it will be found to be travelling more rapidly than at the end of the first. Indeed, it will now be going twice as fast—namely, at the rate of sixty-four feet per second; at the end of the *third* second its velocity will be three times as great,—namely, ninety-six feet per second; and so on. Thus we see that the velocity increases just as the time increases; and if we want to find the velocity at the end of any given time, we have only to multiply by thirty-two the number of seconds during which the ball has been falling. Thus,—

At the end of 1 second, the velocity is $32 \times 1 = 32$ feet per second.
At the end of 2 seconds, the velocity is $32 \times 2 = 64$ feet per second.
At the end of 3 seconds, the velocity is $32 \times 3 = 96$ feet per second.
At the end of 4 seconds, the velocity is $32 \times 4 = 128$ feet per second.
At the end of 5 seconds, the velocity is $32 \times 5 = 160$ feet per second.

And so on. For example, to find the velocity of a falling body at the end of 7 seconds, multiply 7 by 32; this gives 224. At the end of 7 seconds the body will be moving at the rate of 224 feet per second. This uniform acceleration of 32 feet per second, produced by the action of the Earth on falling bodies, is often represented in books on Mechanics by the letter *g*.

47. Space passed over by a falling Body.—After a body has been falling for one second, it is found by experiment to have descended 16 feet. This is nearly true; but the exact distance fallen through in one second depends to a certain extent on the place where the body is dropped. Thus a ball will fall a rather greater distance in one second at the north pole than at the equator. The reason lies in the fact that the force of gravity increases the nearer we get to the Earth's centre. Now, as we are about thirteen miles nearer the centre of the Earth at the north pole than we are at the equator, we find that the force of gravity is a little stronger at the former than at the latter place. Thirteen miles is not much out of nearly 4,000 miles, still it makes a slight difference.

At the end of two seconds the body will have fallen, not 32 feet, as we might think, but 64 feet; at the end of three seconds, 144 feet; and so on. These numbers (16, 64, 144) are in the proportion of the squares of the numbers 1, 2, 3, indicating the number of seconds. Thus, $64 = 16 \times 2 \times 2$; that is, 16 multiplied by 2 squared: and 144 equals 16 multiplied by 3 squared; $16 \times 3 \times 3 = 144$. The rule for finding the distance a body falls from rest in any given time will be: *Multiply the square of the number of seconds by* 16. Thus,—

In 1 second a body falls $16 \times 1 \times 1 = 16$ feet.
In 2 seconds a body falls $16 \times 2 \times 2 = 64$ feet.
In 3 seconds a body falls $16 \times 3 \times 3 = 144$ feet.
In 4 seconds a body falls $16 \times 4 \times 4 = 256$ feet.
In 5 seconds a body falls $16 \times 5 \times 5 = 400$ feet.

And so on.

We may understand the way in which a body falls, under the action of gravity, if we remember that after having fallen 16 feet during the *first* second, the body begins the next with a velocity of 32 feet per second. This velocity alone would carry it over 32 feet during this second; but, in addition, gravity makes it fall as far as it did during the first second, —namely, 16 feet. Thus the total distance fallen in the *second* second will be $32 + 16 = 48$ feet. This, added to the 16 feet it has fallen during the *first* second, gives the 64 feet traversed during the first two seconds. Again: the ball begins the *third* second with a velocity which would carry it over 64 feet during that second; add to this the 16 feet which gravity alone would cause it to fall, and we have 80 feet traversed during the *third* second; this, added to the 64 feet described in the two preceding seconds, gives the total distance of 144 feet passed over *in three seconds*, by a body falling freely from a state of rest.

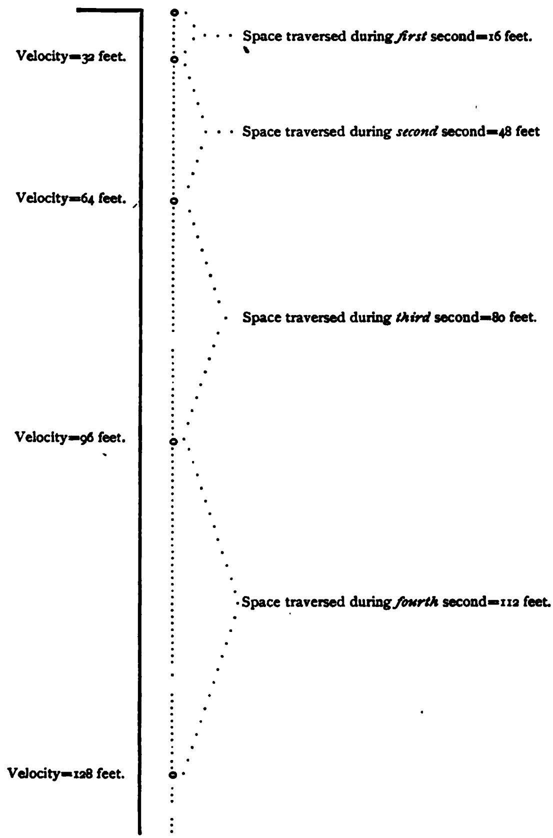

Fig. 16.—Diagram showing the relative Spaces passed over by a Body falling freely from rest, during the first four seconds of its fall. (Scale, ¼ inch to 16 feet.) Total distance traversed = 16 + 48 + 80 + 112 = 256 ft.

48. Problems on falling Bodies.—By the aid of this knowledge several interesting problems may be worked. Suppose, for instance, that a stone is dropped into a well, and that in two seconds it is heard to strike the water. Since in two seconds a body falls through sixty-four feet, we may take that distance for the depth of the well. This is really a trifle too great, because it takes some time, though very little, for the sound of the splash to reach the ear; and thus the real time of the motion of the stone is somewhat less than two seconds. This makes so little difference, however, that in practice we need not notice it.

Again: it is sometimes required to know how far a body falls in some one given second, as, for example, the fourth. Proceeding as above, we find that in four seconds a body falls $16 \times 4 \times 4 = 256$ feet, and that in three seconds it falls $16 \times 3 \times 3 = 144$ feet; therefore during the fourth second it falls $256 - 144 = 112$ feet.

VII.—THE FIRST LAW OF MOTION: INERTIA OF MATTER AT REST.

49. Absolute and relative Motion.—By *absolute* motion we mean the true motion of a body through space, independently of any other motion. When the motion of one body is *compared* with the motion of another, it is called *relative* motion. We know from the science of astronomy that our Earth is not standing still, but that it possesses at least two different motions. (1.) It moves in a circle around the Sun once in a year; and (2.) It turns on its axis once in twenty-four hours. Speaking roughly, we may say that in consequence of the motion around the Sun, the Earth moves through somewhat more than one and a half million of miles in a day. In consequence of the Earth turning round on its axis, a place on the equator also describes in one day a circle, of which the circumference is about twenty-five thousand miles. Now, all people and all things on the Earth have these two motions; and hence, when in common language we say that an object on the Earth is at rest, we mean that it is at rest *as far* *as the Earth is concerned*, and not that it is really or absolutely at rest, for that is impossible. Thus we see that no body on the Earth can be *absolutely* at rest, since all must partake of the Earth's motions. Bodies may be at rest so far as the Earth is concerned, or as compared with other bodies on the Earth; but this is not an absolute state of rest.

In like manner, when bodies fall, the motion we observe is not their whole motion, but only their motion *relatively to the Earth;* for these falling bodies are partaking at the same time of the Earth's motions.

Again: if a box or a parcel be placed on the seat beside a person in a moving train, the box is relatively at rest as far as the person and the other things in the carriage are concerned—it does not change its position with respect to them; but it is in motion compared with the trees and hedges beside the line of railway, and it has in addition the motions of the Earth.

It is true that we do not notice the movements of the Earth, but the fact that we may be in motion and unconscious of it, is established by common observation. For example, let there be two railway trains side by side in a station, and let one of them begin to move; the passengers in both trains are often at a loss to know which of the trains is moving. They see that there is relative motion, but, until they look at some object which they know to be at rest, they are uncertain whether their own train or the other is at rest with respect to the station.

50. The First Law of Motion.—Sir Isaac Newton, to whom we are indebted for a very large part of our knowledge concerning moving bodies, discovered what are called "the laws of motion." These laws are so important, and so many occurrences are explained by their aid, that it is necessary to consider them one by one. We shall now consider the "First Law of Motion." This law states that "*When a body is not acted on by any force, if it be at rest it will remain at rest; and if it be in motion it will continue to move in a straight line with a uniform velocity.*" This is a law which we cannot absolutely *prove*, for we cannot place a body on the earth so that it will not be acted on by any force. Gravity, in the absence of any other force, will always affect the body. In a case of this sort we must take the law as it stands, and try it in as many ways as we can. If it yields satisfactory answers to all our questions, then we are justified in regarding the law as true.

51. Inertia of Matter at Rest.—Let us consider the first part of Newton's law—namely, that "When a body is not acted on by any force, if it be at rest it will remain at rest."

Place a ball on a table. The ball is at rest relatively to the other things in the room. How long will it remain at rest? For ever, if it be not acted upon by some force. We clearly recognize the fact that the ball cannot move of itself. If it does move, we know that some force must have caused it to do so. This property we call the inactivity or *inertia* of matter. The word "inert" is often used to mean dead or lifeless, and matter is inert in the sense that it cannot put itself in motion. Force is always required to produce motion in matter. Hence matter is said to possess the property of *inertia;* and the first law of motion, which states this fact, is often spoken of as the " law of *inertia.*" Let it be clearly understood, however, that inertia does not indicate any unwillingness, as it were, on the part of matter to be moved: it will offer no active resistance to any force acting on it. The law of inertia, when clearly understood, simply means that there is no power residing in matter by which a body can either move itself or bring itself to rest if it be set in motion. A stone can neither start itself nor stop itself; it requires force to set a stone in motion, and it also requires force to stop a moving stone.

52. Illustrations of Inertia.—(1.) If a small weight, as a stone or a piece of lead, be placed on a sheet of paper, when the paper is slowly drawn along the table the stone or the lead will move with it. Gravity is pulling the weight downward, and causing it to press on the paper; and as neither the paper nor the weight is perfectly smooth, there will be a certain amount of rubbing or friction, as it is called, between the paper and the weight. A portion of the force exerted by the hand will therefore be transmitted by the paper to the weight, and will cause it to move along with the paper. But if the paper be pulled with a jerk, it will be found that the weight will be left behind. The reason is, that the friction did not in this case last long enough to pass on to the weight sufficient force to cause it to move along with the paper; and as the weight could not move itself, it was left behind. Instead of saying that the weight "could not move itself," we may say that it has the property of inertia.

(2.) Place a number of small wooden draughtsmen one upon the other, so as to form a small perpendicular column. If the lowest man is pushed gently along, the whole column will move forward, the friction between the men being sufficient to communicate the motion from each man to the one next above it. But if the lowest draught is pushed somewhat more quickly, the friction does not last long enough to pass all the motion to the second; and this one cannot acquire the same velocity, but will move more slowly, and the next draught still more slowly; and so the column will be upset. Finally, if the lowest man be rapidly struck with a thin but heavy body—for example, the back of a dinner knife —it will be seen to fly away, while the column remains undisturbed, and merely falls vertically. Here again we see that the bodies forming the pile cannot move themselves; if they are at rest, and if no force acts upon them, they will remain at rest. This experiment succeeds best if the knife be placed on the table so as to move in a perfectly horizontal direction. With a little practice, a piece may thus be struck even from the middle of a column without upsetting it.

(3.) Lay a card on the top of a wine-glass, and place a coin upon the card. In obedience to the first law of motion the coin will remain on the card for ever, or until some force acts on it. If the card be now smartly struck by the finger, it will be seen to fly off, while the coin will drop into the glass. The friction between the card and the coin was not sufficient to overcome the inertia of the latter; when the card was removed, the coin, being left without any support, fell into the glass. If the coin were closely watched, it would be found to move a little, but not enough to cause it to fall beyond the glass. Instead of one glass and one coin, we might employ two glasses placed side by side, covered with a long card, and having a coin over each glass. This arrangement, however, demands a little more skill to insure success. Instead of using the finger, the card may be struck by a spring, as in Fig. 17.

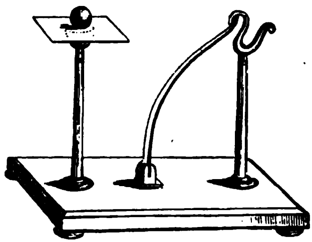
FIG. 17.—Inertia.

(4.) Instances of the action of the law of inertia frequently come under our notice in everyday life. When people are sitting in a train, and the train suddenly moves forward, the bodies of the people, tending to remain at rest, are thrown against the back of the carriage.

(5.) Again: if a man is sitting loosely upon a horse, and the horse suddenly starts forward, the man falls off backward. The man tumbles off in accordance with the first law of motion; for in order to cause him to change his previous state of rest, and move along with the horse, force must be applied to his body. Now, this force can only be applied at those points at which he is in contact with the horse, so that if he is sitting loosely he will fall backwards; but if the man grasps the horse firmly with his knees, he becomes, as it were, part of the horse; the muscular force of the horse is transmitted to his body, and he moves safely along with the animal.

(6.) When a man is standing on the stern of a boat, and the boat is suddenly pushed off, the man's feet partake of the motion of the boat, but his head and body, tending to remain at rest, lag behind, and he may fall into the water.

(7.) If an open vessel, as a cup or a basin, containing some leaden shot or some pease, be moved suddenly and quickly downward, the shot or the pease will be found to linger behind, and to fall into the cup again after it is brought to rest.

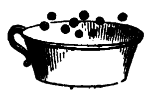

FIG. 18.
Inertia of Pease.

The muscular force of the arm causes the vessel to move, but does not affect the shot. The pellets keep their state of rest, and lag behind until gravity brings them down into the pan. (Fig. 18.)

53. **Practical Applications of Inertia.**—In modern rifles there is a groove cut in the barrel in a spiral manner, designed to give the bullet a twisting motion. If the bullet does not fit tightly, this rotation will not occur, so that it is a point of great importance to get the bullet to fit the barrel perfectly. In the Enfield rifle the bullet is made with a hollow base, and in this hole a wooden plug is loosely placed. When the powder suddenly explodes, the plug is forced forward, and before the bullet has had time to take up the same velocity, the plug forces out

the lower end of the bullet, thus making it fit tightly into the groove of the barrel.

The inertia of water is taken advantage of in the well-known arrangement for supplying railway engines with water while the train is running. The Irish mail runs from Chester to Holyhead, a distance of $84\frac{3}{4}$ miles, in two hours; and the tender (the waggon behind the engine on which are the coals) picks up about 1,000 gallons of water from a long trough, 18 inches wide and 6 inches deep, which is laid between the rails for a length of 441 yards near to Conway. A scoop 10 inches wide dips 2 inches into the water, and is connected with a pipe leading up into the tender. (Fig. 19.) As the engine rushes along, the mouth of the scoop slices off a layer of water; and before the liquid has had time to acquire the velocity of the train, it slides up the few feet of pipe leading to the tender, and rushes into the tank as if it were being discharged from a most powerful force-pump. What really happens is exactly the contrary of what appears to happen. The water is at rest, but the inclined plane formed by the scoop and pipe is pushed underneath it, with a velocity of some forty miles per hour, and the water is lifted into the tender by reason of its inertia.

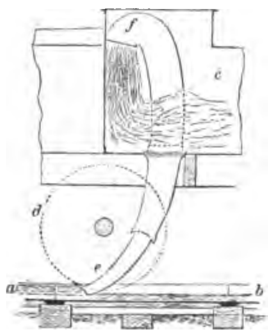

FIG. 19.—Water Scoop. *a, b*, Water-Trough; *d*, Wheel of Tender; *e*, Scoop; *f, c*, Tank inside Tender.

VIII.—INERTIA OF MATTER IN MOTION.

54. The First Law of Motion as applied to moving Bodies.—The second statement in the first law of motion is this, that when a body is not acted on by any force, "if it be in motion it will continue to move in a straight line with uniform velocity." In other words, if a body is in motion it will for ever continue to move in exactly the same manner unless some external force interferes. A moving stone, for example, has no power in itself to go either faster or slower, or to stop; neither can it turn to the right hand nor to the left.

This statement seems quite contrary to our every-day experience. All the bodies which we see in motion on the globe tend, sooner or later, to cease moving. We may make a clock to go for a week, or a month, or even a year, and we admire the steady motion of its wheels; but we know that sooner or later it will stop. All moving things that we see come to rest at last. But why is this? Why do they not move on for ever? It is because we can never place a body where it can be perfectly free. Wherever we may put the body, it will always be acted upon by some force. Do what we can, we can never get rid of *friction.* The moving body is sure to *touch* something else, and wherever it does touch there will be friction; and by friction alone, though unaided by any other force, the body will be brought to rest. The more we can lessen the friction the longer will the body move, and the nearer we shall be to realizing the fact that motion is as natural as rest. It is only in the heavens that we see bodies in motion without friction; and the motions of these bodies—the sun, moon, and stars—seem perpetual. For thousands of years our Earth has been whirling round the sun at the same rate as it does now, and as it will probably continue to do for thousands of years more. Astronomers can foretell with certainty whereabouts in the sky any of the heavenly bodies—the sun, the moon, or the planets—will be next week, next year, or at any more distant time. This is a proof of Newton's law, that "if a body be in motion it will continue to move in a straight line, and with uniform velocity, so long as it is not acted on by any external force."

55. Friction is the great Destroyer of Motion.—We have seen that if a body be stationary, it will remain at rest until it is acted on by some force which can set it in motion. Suppose that a ball is placed on a table: in virtue of its inertia it will tend to remain where it has been placed; but let some force act on it—muscular force, for example. Then we shall see the ball move; but having rolled a certain distance it comes to rest. Why is this? It is because both the table and the ball are more or less rough, and there is a certain amount of rubbing or friction between the table and the ball; it is this friction that sooner or later brings the ball to rest. If such is the case, then if the ball is started with an equal force, on a rougher table it should come to rest sooner, and on a smoother table it should continue in motion for a longer time. If we try these experiments this will be found perfectly true. Thus we see that it is friction that causes the motion of a rolling ball to cease; and the less the friction the longer will the motion continue. We know that if a stone be thrown along a road it soon comes to rest; but if thrown along smooth ice it will travel very much further. From this it seems clear that could we get a perfectly smooth horizontal surface, and a perfectly smooth stone, the motion of the stone would continue for ever. Moreover, the stone would move with uniform velocity and in a true line; for there is no reason why it should become either faster or slower, or why the stone should go off to the right hand or to the left. On the Earth, however, we cannot get perfectly smooth surfaces, or perfectly smooth bodies; and hence all bodies in motion, however great their velocity may be for a time, soon come to rest, their motion being gradually destroyed by friction, if by no other cause.

56. Inertia of Matter in Motion.—It now appears clear that when the motion of a body is changed or is destroyed, it is on account of the action of some outside force. Moving bodies have no power in themselves by which they can bring themselves to rest or cause themselves to move faster or slower. This fact is spoken of as "*the inertia of matter in motion.*" Just as we saw that matter at rest was dead or inert, in that it could not put itself into motion, so matter in motion is inert, for it has the same want of power—it cannot either slacken or increase its speed—it cannot bring itself to rest. Thus we speak of the inertia of matter in motion, as well as of the inertia of matter at rest.

57. Examples of the Inertia of Matter in Motion.—(1.) If a little pan or cup containing pease be jerked upward and then suddenly stopped, the pease will be found to fly out of the pan. At first they move with the same velocity as the pan, but when the pan is suddenly stopped the pease seek to continue their motion, and so leave the pan. They would continue moving upward in straight lines for ever were it not for the friction against the air, and the action of gravity, which at last cause them to stop and to return to the Earth. (See Fig. 18.)

(2.) Fig. 20 shows a piece of apparatus by means of which we may illustrate the law of inertia. It consists of a little circular table of wood, *a*, which can be made to revolve very rapidly by turning the wheel, *b*, the two being connected by an endless band: to a screw in the centre of this wooden disc or table the brass rod, *c*, having a brass ball at the end, is fastened so that it can move freely while the table, *a*, is at rest. Make a chalk mark on the edge of *a*, and place the ball, *c*, over it. When the handle of the wheel, *b*, is turned smartly, the table, *a*, moves also; but the ball, *c*, being at rest, tries to remain at rest, and lags behind, until at length the friction compels it to move with the table. Then, after a time, when table and ball are both spinning round with the same velocity, let the table, *a*, be suddenly stopped by means of the hand, and it will be found that in virtue of its inertia the ball, *c*, will continue moving, until, after perhaps half a dozen revolutions, its motion is destroyed by its friction against the table, and it also comes to rest.

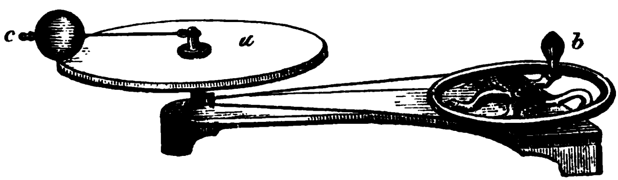

FIG. 20.—Whirling Table.

(3.) A top when spun on the ground speedily comes to rest, principally on account of the friction of its sides against the air and of the point of the peg against the ground. If the friction be made less in any way, the motion will continue for a longer time. For example, if the top be spun a second time upon a smooth surface, as the inside of a watch-glass, it will be found to continue spinning for perhaps five or ten minutes; and if it is spun under a bell-jar which has been exhausted by means of an air-pump, the top will continue to spin, perhaps, for an hour or more.

58. Familiar Illustrations of the Inertia of Matter in Motion.—The people sitting in a railway carriage have of course the same velocity as the train. When a swiftly-moving train is suddenly brought to a standstill the people in it are thrown forward, since their bodies try to retain the motion they had in common with the train. This is the reason why such terrible injuries are often sustained by the passengers of trains which come into collision.

When a vehicle approaches a sharp turn in a road, a cautious driver always slackens his pace for fear of an accident. When the horse is driven round a sharp corner at too high a speed, the carriage, in virtue of its inertia, tends to proceed in the same straight line in which it was previously moving. The consequence is that it overturns, and the passengers are thrown out in the same direction.

Persons who incautiously alight from a train in motion frequently sustain severe falls. The reason is, that a man's whole body when in the train partakes of its motion; but when he jumps out, his feet are stopped by touching the ground, while his body endeavours to move forward with the old velocity. The consequence is that he is thrown down in the direction in which he was travelling.

59. Practical Applications of Inertia of Matter in Motion.—(1.) Every time we use a hammer we take advantage of the force of inertia. If the hammer be merely laid on the nail no effect is obtained; but when the hammer is made to move quickly through the air, on reaching the head of the nail it tends to continue in its state of motion, and in so doing drives the nail into the wood.

(2.) When we wish to fasten the head tightly on a hammer, we knock the opposite end of the handle smartly on the ground, and after one or two blows the head is found to be firmly fixed. The reason is, that the hammer-head endeavours to continue in motion after the handle has stopped, and so fixes itself firmly on the handle.

(3.) The pile-engine, a machine for the purpose of driving large pieces of timber (or piles) into the ground, depends for its utility on the inertia of matter in motion. A heavy piece of iron is raised by means of a chain to a height of several feet, and is then suddenly allowed to fall on the head of the pile. The iron weight, in endeavouring to continue in motion with the velocity it has gained in falling, forces the pile into the earth.

FIG. 21.—Pile-Engine.

(4.) Fly-wheels are large heavy wheels attached to steam-engines, or to other machines that are required to work smoothly and regularly. When a fly-wheel is set in rapid motion its inertia is so great as to compel all the moving parts of the machine to maintain a nearly uniform speed.

(5.) The inertia of water in motion is usefully employed in obtaining a pure water supply for Manchester. The water is obtained from the moorland lying between Manchester and Sheffield, and is sparkling and clear in dry weather, but becomes discoloured by the peat after rain. The question is how to prevent the muddy from mixing with the pure water. Fig. 22 shows the arrangement adopted for a small stream, which flows over a ledge, having an opening at A. When the weather is dry and the supply of water small, the stream flows but slowly, drains through the opening, and falls into the clear-water reservoir: when the stream is swollen by rain, and is therefore muddy, the inertia of the water causes it to leap across the gap, and to pass away in another direction.

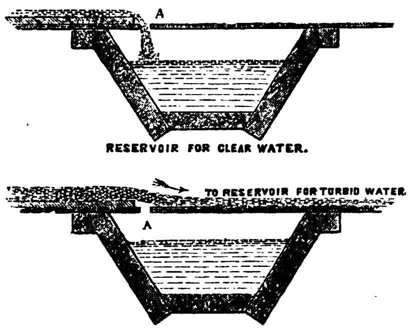

Fig. 22.—Inertia of Water in Motion.

(6.) In the corn warehouses at Liverpool the grain is carried on a plain flat band, eighteen inches broad, made of canvas or india-rubber. The band runs on rollers, and is caused to move round and round by means of a steam-engine. The first law of motion is here applied very ingeniously to divert the grain from one path into another during its passage. At the point where the change of path occurs the carrying band is bent a little upwards (Fig. 23). The result is, that as the stream of grain retains the velocity which is given to it by the band, it is carried forward in a jet over the top of the pulley, B, just as if it were a stream of water.

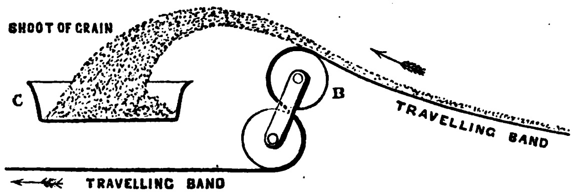

FIG. 23.—Inertia of Matter in Motion.

The spout, C, diverts the corn into a new channel, and may pass it on to another travelling band for transport in a new direction if necessary.

IX.—FRICTION

60. Cause of Friction—61. Disadvantages of Friction—62. Advantages of Friction—63. Kinds of Friction—64. Friction produces Heat.

60. Cause of Friction.—By "friction" is meant the rubbing together of two surfaces. The surface of every body has upon it a certain number of little projections and little hollows, and no amount of polishing, although it may remove the greater number of these irregularities, can render the surface perfectly smooth. The inequalities may be very small, too small to be seen by the naked eye, but they are always present, and may be rendered visible by the aid of the microscope. When any two surfaces are placed in contact, some of the little projections or roughnesses on the one catch in the hollows in the other, and thus the two bodies are held together. When the little projections and the little hollows are of the same shape, as they are in two pieces of the same substance, then they fit closely into one another like the teeth of two similar saws, and are more difficult to separate than they would be if the projections were of different shape to the hollows. Hence it is found that the friction between pieces of the same material is greater than between pieces of different materials. Thus axles of steel are generally made to revolve on brass or gun-metal, and in watches the steel axles of the wheels move in little cups of a very hard stone called agate. When the hollows are filled up with some smooth substance, bodies will slide over one another with greater ease; therefore those surfaces in machines which rub one against the other are often greased or oiled to make the friction less. Of late years black-lead has been employed for the same purpose.

61. Disadvantages of Friction.—A large part of the power used in driving machinery is always lost; that is, it cannot be used in doing the work we desire the machine to accomplish. Wherever two parts of the machine rub together there will always be friction, and some part of the power applied to the machine will be used up in overcoming this friction. This sometimes amounts to as much as one-fourth of the power applied. Again, nearly all the labour expended every year, by men, horses, railway engines, etc., in carrying bodies from place to place, is used in overcoming friction. When we see a horse toiling along a level road with a heavy load in a cart, we know that a child could do the same amount of work were it not for the friction of the wheels against the road and of the axles against the wheels.

62. Advantages of Friction.—Though friction is so great a hindrance to all work, we should be much worse off without any friction at all. Without friction the erection of houses would be impossible; the slightest disturbance would cause them to fall to pieces. We ourselves could not move a step, for it is the friction between our feet and the earth which renders walking so easy to us. We all know how difficult it is to walk upon ice, for the friction between our feet and the ice is very small; but were that friction absent altogether, walking would be quite impossible. Nor could we hold things in our hands: the least force would make them slip through our fingers. It is friction, too, that enables a screw to hold together two pieces of wood. Again, when we drive a wedge into a block of wood, we rely on friction to keep the wedge in its place. When we weave the short fibres of cotton or wool into long threads, it is the friction between the fibres which makes them hold together. What we generally require is a certain amount of friction, but not too much. Our roads must not be too rough and stony, for then the friction against wheels and feet would be too much; but, on the other hand, their surface must not be smooth as glass or as ice, for then the friction would be too little, and we should all slip or slide about.

63. Kinds of Friction.—Friction is usually said to be of two kinds—namely, sliding friction and rolling friction. When one surface slides over another the friction is called *sliding friction* (Fig. 24). Thus sliding friction is produced when a log of wood is dragged endways along a road, or when a rope is pulled

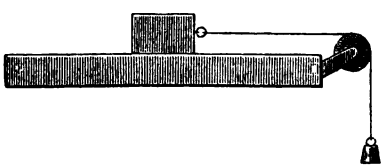

FIG. 24.—Sliding Friction.

through the hands. *Rolling friction* is produced when a body turns round and round, moving onward at the same time, as when a wheel rolls over the ground. Rolling friction is very much less than sliding friction, for the inequalities on the touching surfaces are not *dragged* but *lifted* out from one another. Thus, in an experiment which was actually tried, a roughly-chiselled block of stone weighing 1080 lbs. was made to slide over a stone surface by a force of 758 lbs. The stone was next placed on a wooden sledge, and then a force of 606 lbs. was sufficient to make the loaded sledge slide over a wooden floor. When the wooden surfaces in contact were smeared with tallow the force necessary to draw the stone was reduced to 182 lbs. Finally, when the stone was placed on wooden rollers three feet in diameter, the force necessary to move it was reduced to 28 lbs. only.

In this experiment we have an illustration of what is generally done in every-day life. Whenever we can, we substitute rolling friction for sliding friction. Thus, except when the ground is covered with snow or ice, we always use wheeled carriages to convey materials from one place to another. A labourer puts rollers under heavy blocks of stone, in order to shift them more easily from place to place; and we mount our chairs and tables on castors that they may be easily moved about.

At other times, however, we find it convenient to change the rolling friction into sliding friction. Thus when a laden waggon is moving down a hill, the drag is placed under one wheel in order that the extra friction so produced may check too rapid motion. In other vehicles a brake is applied to the rim of the wheel for the same purpose. The brake generally consists of a block of wood, which can be caused to rub against the circumference of the wheel when it is desired to slacken speed.

64. Friction produces Heat.—Any one who has watched a heavy waggon with the drag under one wheel coming down a stony hill, cannot have failed to see the sparks fly, and the ground smoke after the passage of the drag across it. This indicates the fact that friction is a powerful agent in the production of heat; indeed, the old method of obtaining a light by the aid of flint and steel was only a means of utilizing the heat resulting from the friction of the steel against the flint. Similarly the Indians of North America can obtain a light by rubbing one piece of stick upon another. The friction of a railway-carriage wheel on the metal rails is very small, but the metals are always found to be heated after the passage of a train; and the sparks and flames which often come from the brake when it is necessary to suddenly stop a train give us an idea of the heat that can be generated by friction.

X.—MASS AND MOMENTUM.

65. Definition of Matter—66. Bodies, Particles, and Molecules—67. Volume of a Body—68. How the Masses of Bodies are compared—69. Momentum—70. Examples of Momentum.

65. Definition of Matter.—Matter may be defined to be "that which affects our senses." Thus, if we take an apple in our hand, the sense of touch tells us that it is round and smooth. By the aid of the sense of sight we perceive its red colour. Our nose informs us of its pleasant smell; and should we place a portion of it in our mouth we learn at once that it has an agreeable taste. Since the apple affects our senses, we say it is a piece of matter. It is not necessary that all the senses should be affected. A stone, for example, would probably not affect the sense of taste; the air does not affect the sense of sight; and we cannot smell a piece of iron: but inasmuch as we detect these substances by the aid of one or more of the senses, we call them all *matter*. Again: we have learned that the force of gravity attracts all things towards the centre of the Earth, and that the force with which any substance presses downward is called its weight. It is clear, therefore, that all matter must have weight. Further, we may say that matter exerts force. Thus the Earth, which is a large ball composed of various kinds of matter, exerts the force called Gravity; a magnet made of the matter called steel exerts the force of Magnetism; and a stick of sealing-wax rubbed with flannel exerts the force of Electricity. Not only does matter exert force, but force always acts on matter. We cannot recognize force, indeed, except when it is acting upon matter. Thus we should know nothing about the magnetism in the magnet did we not see its action in attracting pieces of iron; nor about the force of gravity, were it not that we recognize its effects on bodies placed near the Earth. The force itself is entirely beyond our observation. We can only form ideas about it by studying its action upon matter. We may sum up our knowledge by saying that matter is that which affects our senses, which has weight, which exerts force and is acted upon by force.

66. Bodies, Particles, and Molecules.—A portion of matter large enough to be handled is called a *body*. Thus a stone, a tree, or an orange, might be called a body. But any body may be broken up into many smaller parts, as a piece of sugar would be by crushing it or by grinding it to a powder. The portions so obtained, too small to be handled, but large enough to be seen, are generally called *particles*. Now take the sugar particles, and drop them slowly into water. They will gradually disappear, dissolving, as we say, in the water. What has really happened is that the particles of sugar have been broken up into still smaller pieces by the water—into pieces too small to be seen. These are the smallest pieces of sugar that can be obtained, and are called *molecules*. Thus a particle may be said to be built up of molecules, and a body to be made of particles.

67. Volume of a Body.—All bodies take up a certain amount of space or room; in other words, they all have a certain size. The amount of space taken up by any body is called its *volume*, and is measured in cubic feet or cubic inches. Thus a piece of coal of the shape of a brick, and measuring three inches every way, would have a volume $3 \times 3 \times 3 = 27$ cubic inches.

68. How the Masses of Bodies are compared.—The quantity of matter which any body contains is called its *mass*. The quantity of matter in two cubic inches of iron is twice that contained in one cubic inch; therefore the mass of the former is twice that of the latter. But the mass of a body is not always in proportion to its volume. A piece of wood of twenty cubic inches would have less matter in it, and therefore less mass, than one cubic inch of platinum. How, then, are we to estimate the masses of different bodies? We have learned that gravity attracts bodies in proportion to their mass; therefore when any two bodies containing each the same quantity of matter are placed in the oppo-

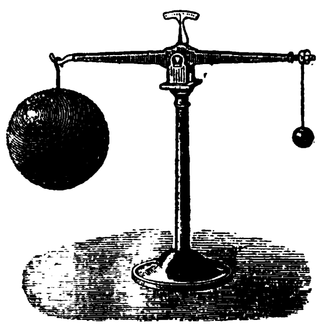

FIG. 25.
Balls of Cork and Lead; equal in mass, unequal in volume.

site scale-pans of a true balance they will be equally attracted by the Earth, and will balance each other whatever their *size* may be (Fig. 25). But the strength of the Earth's attraction for any body is called its weight; therefore mass is usually measured by weight. The unit of mass, or standard of weight, in this country, is defined by Act of Parliament to be a piece of platinum marked "P. S., 1844, 1 lb.;" which is kept in London, and copies of which are preserved in various parts of the kingdom, so that if the original pound were destroyed the others would remain.

It is necessary to understand clearly the difference between the terms *mass* and *weight*. Mass, or the quantity of matter in a body, is something which cannot change, whether the body be at the equator or at the pole, on the Earth or on the Moon; but weight, which is used only as the measure of mass, does vary. Thus a body weighing 200 ounces at the equator would weigh 201 ounces at the pole (tested in a spring balance), for the weight of a body increases by about $\frac{1}{200}$ in passing from the equator to the pole; yet the *mass* of the body would be exactly the same at each place. The mass of a body is invariably the same under all circumstances, but the weight may vary. The weight of a body is used only as the *measure* of its mass, and must not be confounded with mass itself.

69. Momentum.—If a cricket-ball and a cannon-ball of the same size be moving with the same velocity, it will be a much harder task to stop the latter than the former. The cricket-ball may be stopped with the hand, but it will be found impossible to stop the cannon-ball in the same way. Why is this? The answer is plain—that in the cannon-ball there is more force than in the cricket-ball, just as there is more heat in two gallons of water than in one gallon, though both may be of the same temperature.

In studying bodies in motion we soon learn that we have to pay attention to two things—the *mass* of the body in motion, and the *velocity* with which it is moving. If a piece of matter weighing one pound were moving at the rate of one foot per second, it would possess a certain quantity of motion; if it were moving at the rate of ten feet per second, it would have ten times the quantity: now if a body weighing ten pounds were moving at the rate of one foot per second, it also would have ten times the quantity of motion of the body weighing one pound and moving at the same rate. The quantity of motion possessed by a moving body is measured by multiplying the weight of the body expressed in pounds by its velocity measured in feet per second. The number so obtained expresses the *momentum* of the body. The unit or standard of momentum is the quantity of motion possessed by a body weighing one pound and moving at the rate of one foot per second.

70. Examples of Momentum.—(1.) A body weighing one hundredweight, and moving at the rate of nine feet per second, possesses double the momentum of a body weighing half a hundredweight and moving with the same velocity; for the quantity of motion in the former will be $112 \times 9 = 1,008$ units; while that of the latter will be $56 \times 9 = 504$ units.

(2.) The momentum of a cannon-ball weighing 64 lbs., and moving with a velocity of 1,500 feet per second, is $64 \times 1,500 = 96,000$ units.

(3.) The momentum of a train weighing 200,000 lbs. (or about 90 tons) and travelling 30 miles per hour (that is, 44 feet per second) is $200,000 \times 44 = 8,800,000$ units. From this we can understand the terrible results which follow when two heavy trains dash into each other.

(4.) Two icebergs (weighing thousands of tons each), though moving but slowly, can crush the strongest iron-clad between them as we crush an egg-shell between our fingers: their great mass makes up for their small velocity.

(5.) It is often noticed that small, light boys, dodge much better at football or other games than big, heavy lads. The reason is that their momentum is less, and it therefore requires less force to change their course. Hares, too, often escape from the hounds by doubling; that is, by turning quickly on one side and running in a new direction. The hound, with his heavier body and greater speed, has much greater momentum than the hare; and, when the hare has doubled, this momentum takes the hound many yards onward in a straight line before he can alter his course and chase the hare anew.

XI.—COMPOSITION AND RESOLUTION OF FORCES.

71. Representation of Forces—72. Forces acting in the same Direction—73. Forces acting in opposite Directions—74. Forces acting in parallel Lines—75. Forces acting at an Angle with one another—76. Resolution of Forces.

71. Representation of Forces.—Force has been defined to mean "*That which moves or tries to move a body, or which changes or tries to change the motion of a body.*" In talking about forces it is frequently found convenient to represent them by lines drawn upon paper, forming what is called a diagram. But before this can be done it is necessary that we should know three things about the force we are dealing with:—(1.) The point of application of the force; (2.) The direction of the force; (3.) The magnitude of the force.

(1.) *The point of application of the force.*—All bodies, as we have seen, are made up of particles. By the point of application of any force we mean the position of that particle of the body on which the force acts. This particle we may represent on a piece of paper or on a slate by a *dot*, and this dot will then indicate the point of application.

(2.) *The direction of the force.*—When a force is acting on a body, it moves or tends to move the particle on which it acts in a certain direction. The line along which the particle moves, or tends to move, is called the direction of the force. If a line be drawn from the dot which represents the point of application of the force, in the direction in which the particle is caused to move, it will represent the direction in which the force acts.

(3.) *The magnitude of the force.*—We measure a force by saying how many pounds weight it can support. Thus the force which the muscles of a man's arm can exert may be measured by the weight he can lift. If a weight be suspended from an india-rubber or a steel spring, it is evident that the weight will stretch the spring, until the weight pulls the spring down and the spring pulls the weight up with equal force; hence the number of pounds in the weight is the measure of the force the spring is exerting. Now, in our diagram, if we fix on a line of a certain length and agree that it shall represent a force of one pound, we can represent the magnitude of any force by taking as many of these lengths as there are pounds in the force. Let us suppose, for example, that a force of three pounds is applied at the point A (Fig. 26) tending to make A move in the direction A B. A standard line (C) of a certain length (say half an inch) is taken to represent a force of one pound. A dot

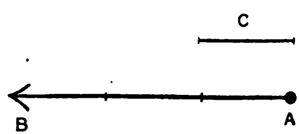

FIG. 26.

C, The Standard line, half an inch in length, representing a force of one pound. A, The Point of Application. A B, Line one inch and a half long, representing a force of three pounds acting on the point A, in the direction A B.

placed at A will represent the *point of application* of the force; the line AB bearing the arrow-head represents its *direction;* and if AB be made three times the length of C (that is, one inch and a half), it will indicate the *magnitude* of the force. Thus the line AB completely represents the force in question.

72. Forces acting in the same Direction.—Take a spring balance and hang on the hook a weight of two pounds. Here we have a force of two pounds acting downward, and to represent it we must draw a line, BD (Fig. 27), from the point of application, B, and twice the length of A, which represents a force of one pound. Now, place on the hook a second weight, also of two pounds; this force will act in the same direction as the first, and we can represent it by continuing the line BD to C, and by making DC equal to twice A. The whole line BC now represents the two forces, and from it we learn that they are together equal to one force of four pounds acting in the same direction (BC). We can test the accuracy of this statement by putting a four-pound weight in place of the two two-pound weights on the spring balance, and we perceive that the pointer marks the same place on the scale as it did before.

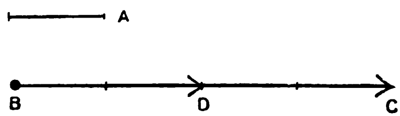

FIG. 27.

A, Standard line (½ inch) representing a force of one pound. BD, Line one inch long, representing a force of two pounds. DC, Line one inch long, representing a second force, also of two pounds. BC, Line two inches long, representing a force of four pounds, acting on the point B in the direction BC. This line represents the resultant of the two forces BD, DC.

Here, then, we have one force equal to two others and producing the same result. This single force is called the *resultant* of the other two forces, and its magnitude is found by adding the former forces (its components, as they are called) together. For example, three men pulling at a rope in the same direction, one with a force of ten pounds, another with a force of fifteen pounds, and a third with a force of twenty-five pounds, would, by their united efforts, produce on the rope a strain of fifty pounds, which might be called the resultant of the three forces.

73. Forces acting in opposite Directions.—The individual forces, however, though acting in the same straight line, may be acting in *opposite* directions. Let us examine this case. In Fig. 28 we have represented two equal weights, A and B, to which strings are attached. These strings, after passing over pulleys, are fastened in a knot (C). This knot is pulled by two equal and opposite forces. Let us mark off CD, CE to indicate the forces. Since there is no reason why C should move to one side more than to the other, it remains at rest. Two forces counteracting each other in this way are said to be in *equilibrium*; they must be equal and opposite. If the forces are made unequal by placing an additional pound on one of the hooks, say on B, the knot will no longer remain at rest. It will then move in

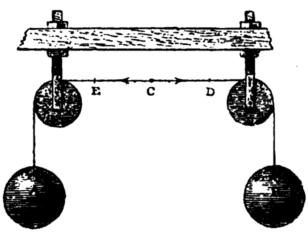

FIG. 28.
Equal Forces acting in opposite directions.

the direction of the greater force. If we have a force of one pound acting in the direction CE and a force of two pounds in the direction CD, they might be replaced, and exactly the same effect produced, by a force of one pound acting in the direction CD. This last-named would be the resultant of the two other forces; and, since the original forces are acting in opposite directions, the magnitude of their resultant is found by *subtracting* the lesser force from the greater. Thus, in Fig. 28, if A were five pounds and B three pounds, the resultant would be a force of two pounds acting along CE.

74. Forces acting in parallel Lines.—Forces that act in the same direction but not in the same straight line are often called parallel forces, since they act in parallel lines. They may be represented as before by lines of proper length drawn in the direction in which the forces act. Thus let AB (Fig. 29) represent a wooden rod; let a force (AP) of two pounds act at A in the direction AP, and a force of three pounds (BQ) act at B in the direction BQ, parallel to AP. These two forces will be together equal in their effect to one force of five pounds (CR) acting at C in the direction CR. This force R is the resultant of the other two forces,

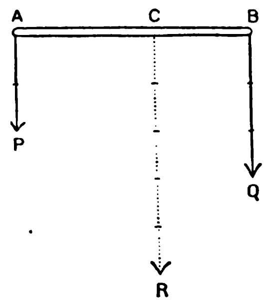

FIG. 29.

AB, Wooden Rod, acted on by the two parallel forces AP (two pounds) and BQ (three pounds). The single force CR (five pounds) would produce the same effect as the two force AP and BQ; it is therefore called their resultant. In this diagram a force of one pound is represented by a line one-quarter of an inch in length.

and its magnitude is found by *adding* the force P to the force Q. The following experiment will help to make this clear:—In Fig. 30, AB is a bar of wood supported by cords passing over pulleys at C and D, and having scale-pans attached to the cords. In the scale-pan P place a one-pound weight, and in the pan W a three-pound weight, and hang a four-pound weight on AB at *f*. The three weights will be found to balance one another on being left free. That is, the weights P and W, of one and three pounds respectively, which tend to pull the bar up-

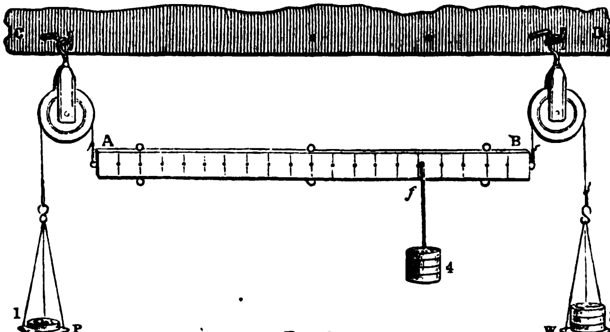

FIG. 30.

ward, are balanced by a single weight of four pounds acting downward from *f*. Instead, therefore, of the two forces P and W, we might have a single force of four pounds acting *upward* from *f*. This last force would be the resultant of the other two forces, and would be equal to their *sum*.

But the forces, though parallel, may act in *opposite* directions. Thus in Fig. 30 the forces P and W actually act upward on the rod, while *f* acts downward; and these three forces are in equilibrium. But add one pound more to *f* and the rod will move downward. In that case we should have two forces of three pounds and one pound respectively acting upward, and a single force of five pounds acting downward. The resultant force would be found by subtracting the sum of the two smaller forces from the greater force, and it would act in the direction of the greater. Thus the resultant of the three forces in this last example would be a force of one pound acting downward.

75. Forces acting at an Angle with one another.—We have an example of forces acting *at an angle* with one another when two boys at the same moment strike a ball, A (Fig. 31), one urging it in the direction AB and the other trying to send it in the direction AC. It is easy to see that the ball will then move along a line somewhere between the two lines AB and AC—along the line AD, for instance. But to understand the exact direction which the body would take and the velocity with which it would move requires a knowledge of the parallelogram of forces and the parallelogram of velocities. These we shall not explain at present, but they will be considered in the third part (Third Year's Course) of this book.

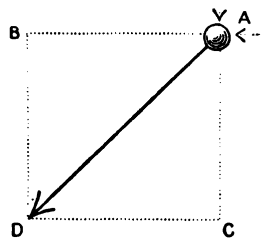

FIG. 31.

If the ball, A, is acted on at the same moment by two equal forces, one acting in the direction A B, and the other in the direction A C, the ball will move in the direction A D.

76. Resolution of Forces.—We have learned that several forces may be *combined;* and we are able to find the *single* force, or resultant, which is equal to several forces acting either (1) in the same direction or (2) in opposite directions. But it is also possible to *resolve* a single force into two or more other forces, whose combined effect will be equal to that of the one original force: this process is called the resolution of forces. For example, we can imagine a man pulling a truck with a force equal, say, to one hundred pounds: if we now replace the man by two boys of equal strength, who are able together to pull the truck with a force exactly equal to that of the man, we shall have replaced the one force of one hundred pounds by two forces of fifty pounds each. We might then say that we had *resolved* the one great force into two other smaller forces.

XII.—THE SECOND LAW OF MOTION.

77. Effect produced by a Force acting on a Body in Motion—78. Forces acting in the same Direction—79. The Velocity of a falling Body is in accordance with the Second Law of Motion—80. Forces acting in opposite Directions.

77. Effect produced by a Force acting on a Body in Motion.—We have already learned something about Newton's first law of motion, and we must now consider the second law which he discovered. In his first law Newton describes what would happen if no force acted upon a body. In the second law of motion a force is supposed to have acted on a body, and to have set it in motion; and while this motion continues, a *second* force is supposed to act on the body. Now, what effect will this second force produce?

We have the answer to this question in Newton's second law of motion, which says that "*When a force acts upon a body in motion, the change of motion is the same in magnitude and direction as if the force acted upon the body at rest.*"

78. Forces acting in the same Direction.—There are three cases to be considered under this law: First, that in which the forces cause motion in the same direction; secondly, that in which the forces act in opposite directions; and, thirdly, that in which the forces act at an angle with one another.

Suppose that a boy strikes a ball with his bat, so as to make it travel with a velocity of ten feet per second, and that, while it is going at this speed, another boy strikes the ball in the same direction just as hard as the first one did. Its velocity will then be twenty feet per second. Here the second force, acting on the body in motion, has evidently produced its full effect; or, in other words, has produced a velocity the same "in magnitude and direction as if the force had acted on the body at rest."

Another illustration may be found in the motion of a boat on a running stream. Suppose that in still water the rower can propel his boat with a velocity of five miles per hour, and that he is about to row in a stream which runs at the rate of four miles per hour. When he rows in the direction in which the current is flowing, the force of his muscles and the current of the stream each produces its full effect, and the boat travels at the rate of $5 + 4 = 9$ miles per hour. This latter velocity may be termed the *resultant* velocity; and the process of combining the two velocities to produce this resultant may be called the composition of velocities, just as in the preceding chapter we had the composition of forces and the production of a resultant force.

79. The Velocity of a falling Body is in accordance with the Second Law of Motion.—Another illustration of the second law of motion will be found in the consideration of the velocity of falling bodies. Suppose that the force of gravity acts for one second upon a body. During this second the body will fall a distance of sixteen feet, and will have acquired a velocity of thirty-two feet per second. If gravity then suddenly ceased to act, the body would fall thirty-two feet during each succeeding second. Gravity, however, does not cease, but acts during the next second just as it did during the first. During the *second* second, therefore, the body will fall through thirty-two feet in virtue of the velocity it had at the end of the *first* second, and through an additional sixteen feet in virtue of the continued action of gravity; making a total distance traversed during the *second* second of forty-eight feet. At the end of the *second* second it will have a velocity of sixty-four feet per second, which would carry it through sixty-four feet in the *third* second; but the force of gravity urges the body through sixteen feet in this third second just as in the first, causing the total distance traversed in the *third* second to be $64 + 16 = 80$ feet. Hence we see that a force acting on a body in motion will produce its full effect, apart from any motion the body may already have; in other words, it will produce exactly the same effect as if it acted on the body at rest. The rule, then, for finding the resultant velocity of a body urged onward by more than one force in the same direction, will be to add together the velocities that the forces would produce if they were to act separately on the body at rest.

80. Forces acting in opposite Directions.—The second case is that in which, when a body is moving with a certain force (which has produced a given velocity) in one direction, another force acts on it from the opposite direction.

A boatman rowing *against* the stream is a good example of this. If he pulls at the rate of five miles per hour, while the stream runs at the rate of four miles per hour, we may suppose that his strength produces its full effect in moving the boat five miles up the stream, but during the hour spent in doing this, the current carries him four miles in the opposite direction; and hence at the end of the hour he will be found only one mile above his starting-place. The rule for finding the resultant of velocities acting in opposite directions is, subtract the smaller velocity from the greater. The motion will take place in the direction of the greater, with the velocity of the difference.

Again: suppose two balls of clay of the same mass to be rolling toward each other, one with a velocity of five feet per second, and the other with a velocity of twenty feet per second. When they meet, the velocity of the first will neutralize, as it were, five feet per second of the velocity of the other ball, which will be left with a velocity of fifteen feet per second. This will be divided equally between the two balls, which will consequently roll away each with a velocity of seven and a half feet per second, in the direction in which the swifter ball was moving when they met.

In the case of bodies thrown upward we have another instance of a force acting on a body in motion, in a contrary direction to that in which the body is moving. By muscular force we can cause a ball to rise through the air; but all the time that it is rising, another force—the force of gravity—

is pulling it down. The muscular force only acts on the ball for a moment; but the force of gravity is a constant, never-ceasing force, and it *continues to act* on the ball all the time it is rising. The upward motion of the ball is consequently soon stopped; and as soon as this happens (for the force of gravity is then opposed by no other force), the ball is drawn to the Earth again.

In all our movements on the Earth we illustrate the second law of motion, since, in addition to the motion of our bodies caused by our own muscular force, we partake of the motions of the Earth. Thus, when we jump, we fall again on the same spot of ground. People have not always remembered this. A man once proposed to cross the Atlantic Ocean by going up in a balloon and waiting in the air till America came under him! He forgot that his balloon, with the air and all things near the Earth, would move on in exactly the same way as the Earth itself.

XIII.—THE THIRD LAW OF MOTION.

81. Action and Reaction.—If we take a strong spring balance and place a weight on the hook, gravity, acting on the iron weight, causes it to stretch the spring and move downward. But when the weight has moved a certain distance downward, it comes to rest. The cause of this stoppage is, that in addition to the action of gravity pulling downward, we have the opposite action of the spring pulling upward; and when the weight comes to rest, these two forces are in equilibrium. Instead of using the words "opposite action," we may say *reaction*, which means the same thing (Latin *re*, back or opposite); and we can express what happens by saying that when the weight is in equilibrium it is because the *action* of gravity and the *reaction* of the spring are equal and opposite.

82. Newton's Third Law of Motion.—Newton's third law of motion states, that "*To every action there is an equal and contrary reaction;*" so that what we found to be true in the case of the spring and the weight, we shall find to hold good in all cases. Let us take another illustration. If a piece of iron be suspended by a thread, and a magnet be brought near it, the iron will be attracted toward the magnet. If the magnet be now suspended, the iron will be found also to attract it. The action of the magnet on the iron and the reaction of the iron on the magnet are equal. If the iron be placed in a scale-pan and balanced by a one-pound weight, we will say, placed in the opposite scale, it will require, perhaps, a second pound weight to balance it when the magnet is brought underneath the scale-pan containing the iron. If the magnet and the piece of iron are then made to change places, exactly the same extra weight will be found necessary to restore equilibrium when the iron is brought below the scale-pan containing the magnet as when the magnet was brought below the balanced iron. Action and reaction, therefore, are equal and opposite in this example also.

83. Illustrations of the Third Law of Motion.—(1.) If a boy press with his two hands against a wall, the wall will be found to press with equal force against him; and if he suddenly increase his pressure, the *reaction* may become so great as to force him backward away from the wall.

(2.) So, too, if a boy wishes to break a piece of cord, he may pull at one end, and may get another boy to pull equally hard in the opposite direction. But he would have had the same power for breaking the cord if he had tied one end to the wall, and himself had pulled as before at the opposite end; for the reaction of the wall would have done the work of the second boy, and would have pulled in the opposite direction with a force equal to his own.

(3.) When a ball is held in the hand, the force of gravity exerted by the Earth draws it downward; but does the ball pull the Earth upward? Yes; and when the ball is set free, the Earth is drawn upward by the ball, just as the ball is drawn downward by the Earth. But how is the motion to be measured in each case? It must be measured by the momentum (or quantity of motion) of the two bodies. When they meet, their momenta will be equal. As the mass of the Earth is so much greater than the mass of the ball, the velocity of the Earth will be proportionally less than the velocity of the ball. The ball, if it has been falling downward for one second, will be moving at the rate of thirty-two feet per second; but the upward velocity of the Earth will be so small as to be inappreciable. From this we see that one body cannot attract another without being itself attracted by that other body; in other words, we cannot have action without reaction; the one always accompanies the other, and they are always equal and opposite.

(4.) The attraction of the Earth and the Moon is mutual; the Earth attracts the Moon and the Moon attracts the Earth; but as the Earth is much the larger and heavier body, the motion of the Moon is affected far more than the motion of the Earth. By reason of the Earth's greater mass, the Moon is caused to circle round the Earth. And just as a boy pulling at a man's coat draws the coat away from the man by his reaction, though he may be compelled to move after the man, so the reacting force of the Moon draws towards it the waters of the ocean—the loose jacket of the Earth, as it were—and produces the phenomenon of the tides.

(5.) When a gun is fired, we have not only the action of the powder in forcing the bullet out of the muzzle, but we also have an equal and contrary reaction in the recoil (or "kick," as it is sometimes called) of the gun against the shoulder of the person who is firing it. If we suppose the mass of the gun to be one hundred times that of the bullet, then the velocity with which the gun is forced back against the shoulder will be only $\frac{1}{100}$ of that imparted to the bullet.

(6.) Many more instances of the third law of motion might easily be found, but we shall only mention two others. A sky-rocket when fired shoots high into the air, from the reaction of the force with which the exploding gas, rushing out at the lower end of the rocket, pushes against the air.

(7.) When a man jumps out of a boat, the action of his feet sends him on to the bank; but there is an equal reaction in the opposite direction, and the boat is seen to move away from the shore.

XIV.—WORK, AND HOW TO MEASURE IT.

84. Definition of the Term "Work."—The word *work* is one which we use daily, and to which we assign various meanings. By work a carpenter means making doors and windows, and so on; a bricklayer calls laying bricks and making mortar, work; while by work a clerk would mean the writing of letters and the making up of accounts. In short, any occupation which causes mental or bodily fatigue is commonly called work. In Mechanics, however, the word has only one meaning—namely, that "*work is the production of motion against resistance.*"

Let us consider this definition. Suppose a four-pound weight to be on the floor with a stool beside it; if the weight be raised from the floor and placed upon the stool, we shall readily admit that work has been done. For in virtue of its inertia the weight will remain on the floor until some force acts upon it. We may apply muscular force to the task of raising the weight; but we shall not succeed unless the muscular force is sufficiently strong to overcome the resistance offered by gravity to the raising of the weight. Since we cause the weight to move in spite of that resistance, we do mechanical work.

85. Cases in which no Work is done.—By keeping the above definition closely in view, we shall find that there are many cases in which, at first sight, work appears to be done, while in reality none is performed. Thus, when the weight has been placed on the stool, it would appear as though the stool were doing work in maintaining it in its place against the attraction of the Earth. But since there is no motion, since the weight retains its position, moving neither upward nor downward, no work is being done. In like manner, a man who stands still with a weight on his shoulder is doing no work.

Now let a string be fastened to the weight, and let it be dragged along the top of the stool. We feel a certain amount of resistance to the movement of the iron weight, caused, not by the attraction of gravity, for that is balanced by the reaction of the stool, but by the friction of the rough iron upon the rough wood. If the iron were polished, and if the top of the stool were covered with glass, the friction would be less, and in dragging the weight along we should do less work, as there would be less resistance to the motion of the weight. Now suppose that the weight and the stool-top were perfectly smooth, there would be no friction, and however much we moved the weight about we could do no work, as there would be no resistance to be overcome. In pulling a cart along a level road, friction is the only force which the horse has to overcome. When he comes to a hill, however, then the horse has, in addition, the force of gravity to contend with, and the work done in pulling the cart must be greater.

86. Measurement of Work.—When we wish to make a measurement of any kind, it is always necessary first to fix on some standard or unit of what we want to measure. Hence we must fix on a unit of work. To do this it will be necessary to consider both the *motion* of the body on which work is done, and the *resistance* that has to be overcome in order to move it. The first (the motion) can be clearly defined by stating how many feet the body has been moved; and the second (the resistance) will be most easily expressed by comparing it with the resistance to be overcome when a body is raised from the Earth, which resistance we generally estimate in pounds. This resistance is, of course, due to the force of gravity; and since this force is *constant* and *always in action*, it affords the best means of measuring work. The unit or standard of work generally adopted is the work that is done in raising a weight of one pound through a vertical height of one foot. This unit of work is called the foot-pound. If a weight of two pounds be raised one foot, twice as much work will be done as when one pound was raised one foot. Again: if a weight of one pound be raised two feet, it will take twice as much power as is required to raise one pound through one foot. How many units of work will be required to raise five pounds to a height of three feet? To raise five pounds through one foot requires a force of five foot-pounds, and this must be repeated three times before the weight arrives at the required height; hence for the whole operation fifteen foot-pounds of work will be necessary. The rule to find the amount of work required to be done in any case is therefore seen to be—*Multiply the weight* (in pounds) *by the vertical distance through which it is raised* (in feet). Here is an illustration of this rule:—How many units of work will be expended in lifting two hundredweight to a height of fifty feet?

The number of pounds is $112 \times 2 = 224$, the number of feet $= 50$; therefore the number of foot-pounds $= 224 \times 50 = 11{,}200$.

87. What is meant by "One Horse-Power"?—In estimating the amount of work done by machines, the number of foot-pounds often becomes inconveniently large. Hence a measure of work larger than a foot-pound has been established, just as we find it convenient to use the mile as a measure of length in addition to the yard. This larger measure of work is called "one horse-power." But since the power of horses varies considerably, it is necessary to state exactly how much work we understand by a single horse-power. It was James Watt, the inventor of the steam-engine, who introduced this standard of work, and he defined one horse-power to mean 33,000 foot-pounds of work done in one minute of time. This is probably beyond the power of most horses; but it has passed into general use, and is always understood when the "horse-power" of an engine is mentioned. A machine, then, of eight horse-power would be one capable of performing $8 \times 33,000 = 264,000$ foot-pounds of work in one minute. The words "horse power" are often represented by the letters "H. P.," so that an engine of "six H. P." means one of six horse-power.

It will be seen that the idea of *time* is introduced into our definition of horse-power, while it was expressly left out when treating of foot-pounds. This is important, for a child could do the amount of work known as a horse-power if allowed time enough. Thus a boy could easily lift a weight of thirty-three pounds to the height of one foot, thus doing thirty-three foot-pounds of work; and if this were done a thousand times, 33,000 foot-pounds of work would be accomplished. But this would probably take the boy a day or more; while in order to obtain one horse-power of work the 33,000 foot-pounds of work must be performed in one minute.

88. Labour and Time.—Many observations have been made as to the amount of work that can be done by men and animals, and as to the way in which it is performed. Thus the greater part of the labour of walking appears to consist in raising the body a small distance at each step; and a great part of the exertion in throwing up earth with a spade is due to the fact that part of the digger's body has to be raised each time a spadeful of earth is thrown out. Thus the amount of useful work done may be much less than we should be led to expect if we considered only the fatigue of the person who does it. It is found, also, that when a man works so that he can do the greatest amount of work in a day, keeping on day by day for a long time, he must not work too hard nor too long. If he works too hard, he will soon break down; if he goes more slowly and tries to make up for it by working longer, he will not accomplish so much in the long run as one who works at a fair medium pace.

XV.—ENERGY.

89. Definition of Energy—90. Measure of Energy—91. Forms of Energy.

89. Definition of Energy.—In ordinary language, a man is said to have great energy when he is capable of overcoming great obstacles, or of getting through a large amount of work. Thus a blacksmith who shoes two horses while his neighbour shoes one is said to have twice the energy of the other man. In this respect, too, we may compare the energies of men, horses, and machines respectively, measuring the energy of each by the work accomplished. Thus a man and a horse may be employed separately to raise coal from a mine. The horse will raise, perhaps, ten times as much as the man in the same time, and will then be said to possess ten times the energy of the man. Again, a steam-engine may raise a ten times greater weight of coal than the horse could in an equal period of time, and will, therefore, have ten times as much energy as the horse, or one hundred times as much as the man.

From this it will be seen that by energy is meant "*the power of doing work.*" Work has been already defined to be the "production of motion against resistance." The resistance may be of any kind;

but in all cases where a body is moved against some resistance work is done, and the power which overcomes the resistance is called *energy*. Thus, if a bullet from a gun pierces the leaves of a book, the force which the moving bullet possesses will be called energy. If this bullet can pierce three hundred pages while another bullet can pierce only one hundred, the former will be said to have three times the energy of the latter body.

90. Measure of Energy.—We have already learned that to measure the magnitude of any force, we must consider how many units of work it is capable of performing. Thus a force that could raise nine pounds to the height of eight feet might be spoken of as doing $9 \times 8 = 72$ foot-pounds of work. Energy, being the power of doing work, will be estimated in the same way. Thus if two machines are working side by side, and one does twenty foot-pounds of work while the other does ten, the former will have double the energy of the latter.

When we know (1) the velocity of a moving body and (2) its weight, we can easily find (3) how many foot-pounds of work the body is capable of performing; and this is the true measure of its energy. Thus, if two forces act on two bodies of the same mass (say one pound each), causing them to move, the one with a velocity of thirty-two feet per second, and the other with a velocity of sixty-four feet per second, we might at first be inclined to think that the energy of the latter body was only double that of the former; but in fact it would be much more. For if the two bodies were thrown upwards with the velocities of thirty-two feet and sixty-four feet per second respectively, they would rise—the former sixteen feet, but the latter sixty-four feet. In other words, the former would do sixteen foot-pounds of work, and the latter sixty-four foot-pounds (if each body weighed one pound). If, then, in two bodies of equal mass one has *twice the velocity* of the other, it will have *four times the energy.* The energy, in fact, increases according to the *square of the velocity.* The energy of a moving body can only be measured by multiplying its weight by the height through which it would have to fall in order to acquire the velocity which it actually has.

91. Forms of Energy.—The various forces of nature may be considered as so many forms of energy, or sources of power. By considering them under this common name of energy, we shall be able to see more clearly how closely related to one another these forces are.

We will now examine each force as a form of energy:—

(1.) GRAVITATION is one of the most apparent of the forms of energy. All falling bodies owe their energy or power of overcoming resistance to gravitation. This energy is employed in many ways: mills are driven by the energy of falling water; clocks by that of falling weights; and so on.

(2.) COHESION is the attraction of the molecules of a body for one another. When we try to bend, or twist, or lengthen a rod of iron, the resistance we experience is due to this form of energy.

(3.) CHEMICAL ATTRACTION is a form of energy of vast importance. When coal is burned, the carbon of which it is composed joins with the oxygen from the air, and forms a new substance called carbonic acid gas. The force which causes this to happen, and which afterwards holds the molecules of the carbon and the oxygen fast bound together, is known as chemical attraction.

(4.) HEAT is a form of energy that is used in almost all processes of manufacture. Steam-engines owe all their energy to the heat produced by the burning of coal in their furnaces.

(5.) MAGNETISM is the form of energy which causes the needle of the mariner's compass always to point to the north, and thus to guide him across the sea; and by which all magnets are able to attract pieces of iron. Our Earth possesses some of this kind of energy, and it is the action of the Earth's magnetism on the needle that causes the latter to point north and south.

(6.) ELECTRICITY is energy of a very similar nature to magnetism. We are indebted to this form of energy for the electric telegraph and for the dazzling electric light; and we may, perhaps, some day use electrical energy to drive our machinery, in the same way as we use steam-engines now.

(7.) LIGHT. This is caused by an exceedingly rapid motion of the molecules of luminous bodies, transmitted by an extremely thin fluid called ether, which pervades all space. Light is undoubtedly a form of energy. It is the energy by the aid of which plants live and grow, and thus prepare food for men and animals. In photography it is the energy of the rays of light which produces the pictures.

(8.) MUSCULAR ENERGY, or the power possessed by the muscles of living animals, is that form of energy which enables them to move and do work. As it is only possessed by living things, it is frequently called " vital energy," or vital force.

(9.) MECHANICAL ENERGY is a convenient name for the energy that a *moving* body possesses. Thus the energy of an arrow flying through the air is called mechanical energy.

XVI.—POTENTIAL ENERGY.

92. Storage of Energy—93. Examples of Potential Energy—94. The Sun as a Source of Energy—95. Potential Energy of elastic Bodies.

92. Storage of Energy.—To show how energy may be stored up or accumulated in a body, let us take a tripod stand (Fig. 32) supporting a pulley at a height of about nine feet from the ground, and pass over the pulley a rope fifteen feet long, bearing at one end a weight (A) of fourteen pounds, and at the other a weight (B) of twenty-eight pounds. When the whole is left free, the heavy weight will, of course, be upon the ground, and the lighter one will hang about three feet from the ground. Now, let the lighter weight, A, be raised by means of the rope to the height of the pulley, C. To do this we must exert a certain amount of muscular force; enough, in fact, to raise fourteen pounds through a height

FIG. 32.
Potential Energy.

of six feet — that is $14 \times 6 = 84$ foot-pounds. This energy is now *stored up* in the weight A, and by setting that weight free, we can get the energy back again, and use it to perform work. Since this stored-up energy is capable of doing work, it is called *potential energy* (from the Latin *potens*, powerful). Now, set A free, and it will at once commence to fall; but when it has fallen six feet, and is still three feet from the ground, the rope is pulled tight, and it can now fall further only by raising the weight B. This the small weight A is able to do by using the store of energy accumulated in it. We know that eighty-four foot-pounds of energy were stored up in A; and could this all be used in raising B, the latter would rise three feet; for, in rising this distance, $3 \times 28 = 84$ foot-pounds of work (that is, A's whole store) are performed. As a matter of fact, B would not rise quite so high as three feet, for part of A's energy is wasted in overcoming the friction of the pulley and in bending the rope.

93. Examples of Potential Energy.—Energy thus stored up in a body may be used in various ways.

(1.) It is this accumulated or potential energy which enables us to make such good use of the hammer. The hammer merely laid on the head of a nail would have little or no effect on it. We first raise the hammer to a height of one or two feet, thus storing up potential energy in it; and then by suddenly bringing it down we expend this energy (and some of our muscular force also) in driving the nail into the wood. The harder the blow we desire to strike, the heavier do we make the hammer-head and the higher do we raise it, in order to store up in it a greater amount of potential energy.

(2.) The pile-engine is a hammer on a large scale. Piles are long pieces of timber, sharpened at one end and driven firmly into the ground, in order to bear great weights. The pile-engine consists of a tripod frame bearing a pulley, over which a rope passes to a heavy iron block called the "monkey," which represents the hammer-head. (See Fig. 21.) This is raised as high as the pulley will allow, and thus gains potential energy. This energy the monkey gives out when released, by falling on the top of the pile and driving it into the ground. Suppose the monkey to weigh three hundredweight (336 pounds), and to be raised 15 feet; it will accumulate $336 \times 15 = 5040$ foot-pounds of energy, which represents the force of the blow given to the pile to drive it further into the ground.

(3.) When a stone is thrown into the air, it rises for a certain length of time, storing up energy as it goes, until, on reaching its highest point, it is for a moment at rest. If it were caught at that moment and suspended in the air, it might remain at rest for any length of time; but the energy which has been stored up in the stone would not be lost; it would be retained as *potential energy*, which would at once become active if the stone were again set free. Had the stone remained lying on the ground, it would have had none of this potential energy, for it would have had no advantage of position over the other things around it. Its potential energy depends on its *position*, or height above the ground, and potential energy is therefore frequently spoken of as "energy of position." A great stone perched high on a hill-side has, in virtue of its position, a store of energy. This stone may be held in its place by a small stone in front of it, and, thus supported, may remain at rest for ages, until some chance dislodges the small stone. Then the large stone goes thundering down the hill, giving up in its descent the energy of position that has been stored up in it for so long a time.

(4.) A brick on a house-top has energy of position, which was accumulated in it when the labourer carried it up, and which it will retain undiminished until the house is pulled down, and the energy is employed to bring it back to the ground again.

In all these cases the advantage the body has is one of *position* with respect to the Earth and to the force of gravity. Work is expended in raising the body from the Earth; and this work is stored up, as it were, in giving the body such a position that gravity, by causing it to fall, can restore the exact amount of energy expended in raising it.

94. The Sun as a Source of Energy.—The Sun is constantly at work laying up a store of energy for us; and we as constantly take advantage of his labour, by using this potential energy to perform various kinds of work.

Consider the Sun shining on the water of the ocean, and changing some of it into vapour. This vapour rises into the air and forms clouds, and the clouds are drifted by the wind over the land. Here they are condensed, and the water falls as rain on the hilltops, and, running over the surface of the ground, collects in little streamlets. The streamlets unite to form streams, and these go rushing down the hillsides, the potential energy bestowed on the water by the Sun being gradually lost as the river flows downward. Wheels are frequently placed in the course of the streams, and the energy of the streams is used to turn them. Fig. 33 represents one of these water-wheels (called an overshot-wheel, because the water flows over the top, to distinguish it from those in which the water flows underneath, and which are called undershot). The water is carried along a trough to the top of the wheel, and flows into the buckets arranged round its circumference. One side of the wheel is thus made heavier than the other side, and the water, continually falling, causes the wheel to revolve. An axle from the wheel leads to a mill containing machinery whereby the energy once stored up in the water is used, perhaps, to grind our corn. In the famous Falls of Niagara there is an enormous and unfailing supply of energy, and it is now proposed to use it for driving machinery. When our coal runs short, it is probable that many other waterfalls will also be used as sources of energy.

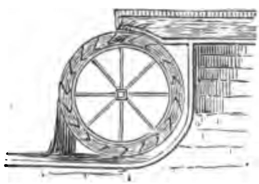

FIG. 33.
"Overshot" Water-Wheel.

95. Potential Energy of elastic Bodies.—Use is sometimes made of the property of elasticity in order to store up potential energy. A bow and arrow is an instance of this. When we wish to shoot with the bow, we first bend it, thereby using our muscular force to overcome the force of cohesion, which endeavours to hold the molecules of the bow in their places, and which also strives to make them return to their old positions when they are moved out of them. In these molecules, now removed from their places, and tugging at one another in their attempt to regain their old positions, we have a store of potential energy, which is set free all at once by liberating the bow-string, and is used to propel the arrow through the air. In a watch-spring we have another instance of energy stored by the aid of elasticity—the watch-spring slowly giving out in a day the potential energy that was accumulated in it during the few seconds occupied in winding up the watch.

XVII.—KINETIC ENERGY.

96. Energy of Matter in Motion—97. Examples of Kinetic Energy—98. Kinetic Energy varies as the Mass of a Body—99. Kinetic Energy varies as the Square of the Velocity—100. Kinetic Energy and Momentum.

96. Energy of Matter in Motion.—We have explained that the word *energy* means the power of doing work, and that *potential energy* is the name for power stored up in a body and ready to be used. By *kinetic energy* we mean energy that is actually being used. The word "kinetic" comes from the Greek word *kineo*, I move; and thus kinetic energy means "*the energy of a body that is in motion.*"

We know that a cannon-ball moving rapidly through the air possesses a great amount of energy, or power of doing work; and we see this energy expended in overcoming, first, the resistance of the air; and, secondly, the far greater resistance of the target. While this energy was stored up in the gunpowder, it was potential energy; now that it is being put forth by the moving ball, we call it kinetic energy. A hammer, poised high in the air by the hand of a workman, has a store of energy in virtue of its position above the nail he intends to strike; but unless he makes it fall through the air on the head of the nail, no work will be done. This energy which the hammer has while descending, and while actually driving in the nail, is an example of what we mean by kinetic energy. Whenever we see work being done, we may be sure that it is kinetic energy that is engaged in doing it, whatever may have been the source from which the kinetic energy was derived.

97. Examples of Kinetic Energy.—(1.) A cricket-ball, as it lies on the ground by the bowler's foot, has neither potential nor kinetic energy; but let a man take it up and throw it at the wickets, then it has kinetic energy, and we see the effect of the work done by the energy of the ball in the falling and perhaps broken stumps. Similarly, when the batsman strikes the ball, he must overcome the kinetic energy imparted to it by the bowler, and give it sufficient energy to carry it in another direction across the field, before he can score a run.

(2.) A stream of water running down-hill has kinetic energy, which carries it onward in its course. If we want to change its course, we must overcome the kinetic energy it has in the old direction, and force it into a new one. We may make use, too, of the kinetic energy of the running water, and cause it to turn mill-stones or other machinery, by placing in its course a water-wheel, which will transfer, as it were, a part of the kinetic energy of the running water to the machinery to be moved. Now, build a dam across the stream above the mill. The water no longer flows, and the mill does no work. What has become of the energy of the mill-stream? It is now being stored up as potential energy in the water behind the dam. Soon, however, the water will rise above the dam, and the potential energy that has been accumulating will be converted into kinetic energy, as we shall see in the downward rush of the water and the sudden turning of the mill-wheel.

98. Kinetic Energy varies as the Mass of a Body.—If a stone weighing one pound and another weighing two pounds fall from the same height, they will each have the same velocity on reaching the ground; but the latter will have twice the energy of the former, because it is twice as heavy. A hammer weighing ten pounds will strike twice as hard a blow as one weighing five pounds, when both are moved with the same velocity. The energy of a moving body, then, depends partly on the mass of the body, or on the quantity of matter it contains. Other things being equal, the body that has the greater mass has the greater energy. It is because the mass of an ironclad ship-of-war is so enormous, that it is able to cut another vessel completely in two, although it may not be moving faster than a boy can run. Its energy depends largely on its mass.

99. Kinetic Energy varies as the Square of the Velocity.—But when the mass remains unchanged, the energy is found to vary with the velocity. Thus a bullet shot out of a gun with a velocity of one hundred feet per second may perhaps pierce a plank three inches thick. If it has a velocity of two hundred feet per second it will pierce, not two, but four such planks; and with a velocity of three hundred feet per second it will pierce nine planks. Thus, by doubling the velocity we have increased the energy fourfold, and by trebling the velocity we make the energy nine times greater. In other words, the energy increases as the square of the velocity.

If a cannon-ball be shot out of a cannon with a velocity of one thousand feet per second, it will travel a certain distance; if, however, its velocity be doubled, it will travel four times the distance (not twice); and if the velocity be quadrupled, it will travel, not four times as far, but four times squared; that is, sixteen times the distance. If the ball be sent upward from the Earth, instead of parallel to it, the same result will be obtained. Thus a ball thrown upward with a velocity of thirty-two feet per second rises sixteen feet. Now double the velocity at starting, making it sixty-four feet per second, and the height reached is quadrupled; that is, the ball rises sixty-four feet. Next, treble the starting velocity, making it sixty-four feet per second, and the height reached will be nine times as great; that is, one hundred and forty-four feet.

100. Kinetic Energy and Momentum.—When a force acts on a body, its effect may be measured either by the quantity of motion, or momentum, imparted to the body; or by the power of doing work, or energy, given to the body.

For example: let a ball weighing two pounds fall for one second under the action of gravity alone; at the end of that time its velocity will be 32 feet per second. Its momentum will therefore be

$32 \times 2 = 64$ units. As it has fallen only 16 feet, however, its energy will be $16 \times 2 = 32$ foot-pounds. Now, let the mass of the ball be doubled; that is, let it now weigh four pounds. If it fall for the same time, both its momentum and its energy will be doubled. The former will be $32 \times 4 = 128$ units, and the latter $16 \times 4 = 64$ foot-pounds. But now, while the mass still remains at two pounds, let the time of falling be increased to two seconds. The velocity will be doubled; that is, it will be 64 feet per second: but the total distance fallen through will be four times as great; that is, 64 feet. The momentum in this case will be $64 \times 2 = 128$ units, and the energy $64 \times 2 = 128$ foot-pounds. At the end of the *first* second the number representing the momentum was double that representing the energy, but at the end of the *second* second they are equal. In other words, by doubling the velocity we have doubled the momentum or quantity of motion, but we have increased the energy or power of doing work fourfold.

The great point to be borne in mind in considering momentum and energy is, that the units employed in measuring each must be clearly understood and kept quite separate. The unit of *momentum* is the quantity of motion in a mass of one pound moving with a velocity of one foot per second; the unit of *energy* is the power required to raise a mass of one pound to the height of one foot. The momentum and the energy must be calculated separately, and we must not confound the *energy* of a moving body with the *momentum*, or *vice versa*.

XVIII.—INDESTRUCTIBILITY OF ENERGY.

101. Energy may be transferred but cannot be destroyed—102. The Energy of the Pendulum—103. Loss of Energy by Friction—104. Energy in a Ball thrown upward—105. What becomes of the Energy of falling Bodies?—106. Energy can be changed from one Form into another—107. Heat changed into Chemical Force—108. The Energy of the Sun—109. The Potential Energy of Coal.

101. Energy may be transferred but cannot be destroyed.—It has long been known that *matter* cannot be destroyed; it may be changed or altered, but it can never be got rid of altogether. It is, however, only during the last thirty years or so that this idea has been extended to *energy*. But we now know that energy cannot be destroyed; and bearing this in mind, many facts can be explained which previously had been matters of wonder even to scientific men.

We have learned that energy is of two kinds:—(1.) Potential energy, or the energy a body has in virtue of its position; and (2.) Kinetic energy, or the energy of matter in motion. The actual energy a body has may be either kinetic or potential, or it may be partly one and partly the other. Now it has been discovered that energy can be *changed* from the one kind into the other in the same body, but that it *cannot be destroyed*. Energy may even be passed on from one body to another, but it will always remain energy of some kind or other.

102. The Energy of the Pendulum.—Perhaps the pendulum affords as good an example of this fact as we can get. When it hangs vertically at rest (PM, Fig. 34) it has no kinetic energy; and if we suppose the cord to be too strong ever to break, it has no potential energy either, since the bob, M, can fall no lower.

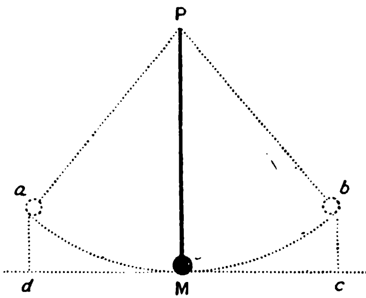

FIG. 34.
Pendulum arranged to swing through the arc *a*M*b*. When swinging (or vibrating), its potential energy is greatest when the bob is at *a* or at *b*; as the bob passes M, its energy is kinetic only.

In order to start the pendulum we pull it to one side, but in so doing we *raise it* vertically through the distance *cb* above its first resting-place at M. To raise the pendulum in this way, we must use a certain amount of force; this force is now stored up in the weight at *b* as so much *potential energy.* Now release the pendulum: its potential energy is gradually changed into kinetic energy, which carries it downward to the point M. When at this point it has no longer any potential energy, but kinetic energy only; still the velocity which it now possesses will exactly represent the potential energy lost, and will carry the pendulum onward to the point *a*, as high on that side as it was on the other side at *b*. When the bob is at *a*, it is for a moment still, and has no kinetic energy, but potential only; just as much potential energy, in fact, as it had when at *b*. And now the bob will fall again, gradually exchanging its potential energy for kinetic, till, when it reaches M, its energy is again all kinetic; then rising towards *b* it will lose kinetic energy and gain potential as it mounts higher and higher, until the change is complete and it is momentarily at rest again at *b*.

103. Loss of Energy by Friction.—In every swing of the pendulum we thus have a change of energy from potential to kinetic, and back again from kinetic to potential. If this change is complete and no energy is destroyed, the pendulum should swing on for ever. But it presently stops. Why is this? The reason lies in the fact that in every vibration of the pendulum a certain quantity of air must be pushed aside. Force is required for this, and also to overcome the friction of the rod of the pendulum on the support from which it hangs. Could this friction be done away with, the pendulum would go on vibrating for ever. But what becomes of the energy used in overcoming the friction? Is it completely lost? No; it is changed into *heat*. Could we collect the heat generated in this way, we should have exactly the same amount of energy as the pendulum has lost, but in another form. The energy has only been changed from one form into another.

104. Energy in a Ball thrown upward.—When a ball is thrown into the air a certain amount of muscular force is exerted. This force is expended in causing the ball to rise in opposition to the force of gravity; and the amount of muscular energy lost by the person throwing is exactly equal to the energy gained by the ball. In rising, however, the kinetic energy of the ball is gradually changed into potential energy, and at a certain point this change is complete. At this point the ball is for a moment perfectly still. Now the reverse change begins to take place. The potential energy is gradually changed into kinetic, and the ball again begins to move; but this time in the opposite direction—namely, downward. At the moment when the ball touches the ground the change is again complete: the kinetic energy at that moment is at its greatest, but on striking the ground it is completely lost. What has become of it?

105. What becomes of the Energy of falling Bodies?—When the ball strikes the ground it comes to rest, having apparently no energy, kinetic or potential. What has become of its kinetic energy? *It is changed into heat;* and the heat developed is exactly equal to the kinetic energy lost by the ball. Could the heat so produced be collected and used in the right way, it would raise the ball again to the height from which it fell. As a matter of fact the heat is carried away by the air and by the ground, so that it cannot usually be recognized. But when a stone is thrown violently upon a hard road, the heat produced is often rendered visible in the sparks which fly around. When a blacksmith hammers a piece of iron, the iron speedily becomes hot; the heat is in reality only the muscular force of the blacksmith changed into another form—first into the visible energy of the falling hammer, and then into that motion of the molecules of the nail which we call heat.

106. Energy can be changed from one Form into another.—In all cases where energy seems to be destroyed, it will be found to be merely *changed* in form. We may not at first recognize the energy that has been produced, but careful attention will generally make this clear.

Thus, when a piece of sealing-wax is rubbed with cat-skin, the muscular force of the person rubbing is changed partly into the force of heat and partly into the force of electricity. We recognize the heat, for both the cat-skin and the sealing-wax feel warm. The electricity, however, may pass unnoticed unless we make some special arrangement in order to render its effects visible. A very simple means of doing this is to place some small pieces of paper on a table and to bring the rubbed wax near them. (Fig. 35.) They will be seen to jump up from the table to the wax, and sometimes to fly away again. The electric energy which causes the pieces of paper to do this is derived from the muscular energy used in rubbing the sealing-wax.

FIG. 35.—Attraction of light bodies by electrified Sealing-Wax.

When we place certain metals, as strips of zinc and copper, into a mixture of sulphuric acid and water, the chemical force begins to act. If we now connect these strips in the manner shown in Fig. 36, we shall obtain a current of electricity which may be able to produce a dazzling light. Here we have the chemical force changing first into the electrical force, and then into the forces of light and heat.

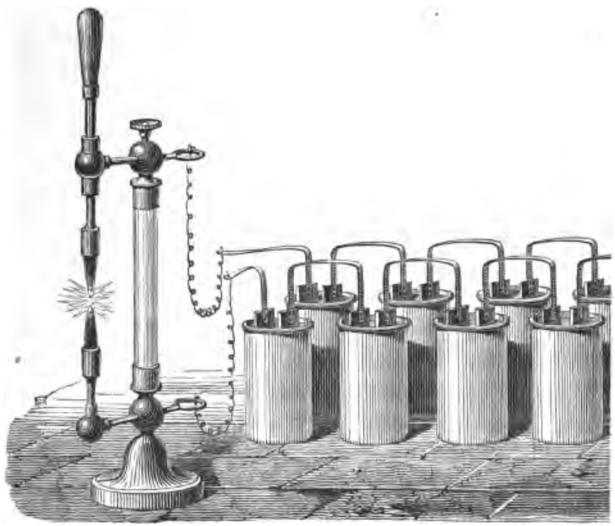

FIG. 36.—The Electric Light as produced by Chemical Action.

107. Heat changed into chemical Force.—When a match is rubbed on a rough surface the kinetic energy of the moving match is changed into heat. We choose a rough surface on which to rub the match, for experience has taught us that a rough surface will change the kinetic energy into heat more rapidly than a smooth one, since the greater the friction the greater is the amount of heat produced. The heat in its turn produces chemical energy, which is the form of energy that causes the phosphorus on the end of the match to join with the oxygen in the air, thus making the match burn. The chemical force continues to act as long as there is any of the match left to be burned; and during all that time is itself constantly being changed, partly into heat, which can be felt by placing the hand near the flame, and partly into light, which illumines the room. The heat produced from the chemical energy can be used to generate more chemical energy; as when we bring the match close to the wick of a candle, which almost immediately bursts into flame, showing us in this way that chemical energy is again at work as it was when the match was burning.

Many more illustrations of the change of one kind of energy into another might be given. In fact, we can change any one force into any other force provided we set about doing it in the proper way. The examples that have been given will be sufficient to point out the great lesson, that energy *may be altered* from one form to another, but can *never be destroyed.* This principle is known as the *conservation of energy.*

108. The Energy of the Sun.—The Sun is constantly supplying us with stores of force. By the aid of its light and heat plants are able to take into their leaves carbonic acid gas from the atmosphere, and to split up this gaseous substance into the carbon and oxygen of which it is composed. The carbon is retained by the plant to form its wood, but the oxygen is returned to the atmosphere. A plant cannot grow in a very cold place or in the dark; it needs the two forces of light and heat to enable it to grow. In decomposing the carbonic acid gas, the plant is making use of the Sun's energy (in the forms of light and heat) to accumulate a store of potential energy; for the separated atoms of the carbon and oxygen are ready at any time to join together again.

109. The Potential Energy of Coal.—In ages long ago countless numbers of plants lived and died, and their wood has been buried deep within the Earth for thousands and thousands of years, becoming at last changed into coal, which consists mainly of the carbon of the plant. At last the coal is dug up and used, it may be, to feed the furnace-fire of an engine. The coal burns; but what do we mean by burning? We mean that the carbon of the coal, joining with oxygen in the air, forms carbonic acid gas and produces light and heat. We are, in fact, bringing together again the very atoms of carbon and of oxygen which the plant, aided by the sunlight, separated so many ages ago; and in doing so we are changing the potential energy then stored up, into kinetic energy, which we may recognize in the moving steam-engine and in the work it accomplishes. It is said that the famous engineer George Stephenson once asked a companion what it was that really moved a railway train. "The engine"—"the coal"—his friend guessed. "No," said Stephenson; "it is 'bottled sunlight'!" And in the main he was right. It was the Sun's energy in the form of light and heat which had enabled the plants whose remains form coal, to obtain carbon from the air in past ages and to form it into wood. We use this carbon to produce heat once more in the engine-furnace, and the heat is then converted into the kinetic energy of the moving train.

XIX.—THE NATURE OF HEAT.

110. What is a "Theory"?—111. The Material Theory of Heat—112. The Mechanical Theory of Heat—113. Expansion of Bodies by Heat—114. Change of State effected by Heat—115. Transmission of Heat by Conduction—116. Transmission of Heat by Convection—117. Transmission of Heat by Radiation.

110. What is a "Theory"?—We must now consider more closely the nature of the force known as *heat.* The effects produced by heat come under our notice every day. Indeed they are so common that they excite no surprise, although most people would be puzzled if they were asked to *explain* some of the simplest phenomena of heat. Why, for instance, do some substances feel hot and others feel cold? Why do two bodies become heated by being rubbed one against the other? This we shall now endeavour to make clear. But before we do so it will be well to explain a word that we shall have frequent occasion to use—the word "theory." A theory is an explanation of a natural occurrence which we find convenient to use when we cannot be absolutely certain what the cause of the occurrence is. Thus, we may never be able to see with our eyes what the cause of heat is, but we may have an idea about it, and the explanation that our idea enables us to give of the nature of heat is called a theory.

111. The Material Theory of Heat.—Two theories have been put forward as to the nature of heat. The one is known as the material theory, and the other as the mechanical theory of heat. The material theory is the older of the two, and it supposed "heat" to be a very thin fluid or gas, much lighter even than hydrogen, which is the lightest substance we know on the Earth. It was supposed that when a body contained a large quantity of this heat fluid—caloric, as it was called—the body felt hot, and that when it contained but little it was cold. Heating a body was supposed to be simply putting more caloric into it; and the cooling of any body was thought to be the result of taking caloric away from it.

The chief objections to this theory are, firstly, that if heat is a substance it ought to *weigh something*, for all matter has weight. It is certain, however, that a body weighs no more when hot than when cold. Secondly, no body can contain more than a certain definite quantity of any substance; but it is possible to produce an unlimited quantity of heat out of any two bodies by simply rubbing them together. It is pretty certain, therefore, that the material theory of heat cannot be true, and that there is no such substance as caloric.

112. The Mechanical Theory of Heat.—The more modern theory of heat is called the *mechanical theory*, for it does not consider heat to be a substance, but *a kind of motion*. We have learned that bodies are composed of very small pieces called molecules. Now heat is thought to be a motion of the molecules of bodies. When the motion of the molecules is rapid, the heat is great; and when a body becomes cold, it is because the molecules move more slowly. We do not know exactly in what way the molecules move, for they are so small that we cannot see them, but it is convenient to think of them as swinging to and fro like little pendulums rapidly vibrating.

This mechanical theory of heat is much preferable to the material theory. It explains *all* the facts connected with heat in a clear and satisfactory way; and when a theory can do that, it is generally accepted as being the true one.

113. Expansion of Bodies by Heat.—By the aid of this theory we can clearly understand why bodies expand when they are heated. Let us take a brass ball (Fig. 37) which just passes through a brass ring when both ring and ball are cold. Now heat the brass ball, and again try to pass it through the ring. It will not go through, for it has grown larger by being heated. When the ball was cold its molecules were moving to and fro with a certain velocity, but when the ball was heated the molecules moved more rapidly and through longer distances. They consequently wanted more

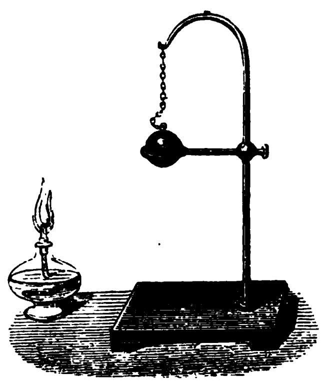
FIG. 37.
Gravesande's Ball and Ring.

room, and jostled against one another, pushing one another further apart, and thus causing the ball, as a whole, to take up more room, or, in other words, to expand.

When the ball is cooled, the opposite change takes place. The molecules vibrate less widely and less rapidly, and thus lie closer together, causing the ball, as a whole, to contract.

114. Change of State effected by Heat.—The molecules of a body are held together by the force of cohesion, while heat, as we have seen, causes them to move further apart. The more the molecules are separated one from another the weaker their cohesion becomes, for the force of cohesion can act only over very small distances. Thus the greater the heat the less is the cohesion. If we continue the heating above a certain point, the force of cohesion will be so far overcome that it cannot keep the molecules in their fixed places, but allows them to roll freely over one another. The body is then changed from the solid into the liquid state.

If the heat be still further increased, the molecules will be driven further and further asunder, and will move about so violently that at last cohesion will be unable to restrain them any longer, and they will fly off from the surface of the liquid into the air. The heat has now changed the liquid into the form of a gas. By cooling a gas—that is, by reducing the motion of its molecules—we can bring it into the liquid state. Then, by still further cooling the liquid, the vibration of the molecules is still more checked, the force of cohesion obtains more hold on them, and the liquid again becomes a solid.

115. Transmission of Heat by Conduction.—When an iron poker is thrust into the fire, the point in the fire soon becomes heated. Before long, however, the knob at the end farthest from the fire also grows hot. The heat must therefore have been conveyed in some way along the poker from the point in the fire to the knob outside. On the principle that heat is due to the vibration of the molecules of a body, we can readily explain the passage of heat along the poker. The heat of the fire throws the molecules of the iron point into a state of vibration. These molecules pass on the motion to the next molecules, and so the vibrations travel along the poker until the molecules of the knob are last of all set in motion. This is called the passage of heat by conduction.

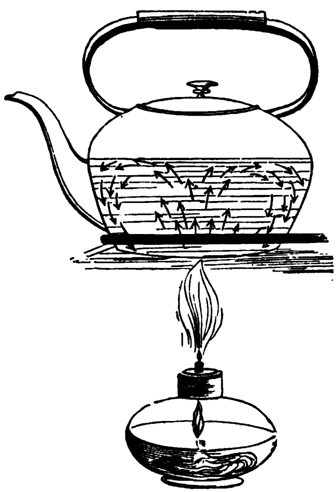

FIG. 38.
Transmission of Heat by Convection.

116. Transmission of Heat by Convection.—Liquids and gases are, as a rule, heated in a very different way to that just described. When a kettleful of cold water is put on the fire, the water next the bottom of the kettle is the first to become hot. The heat drives the molecules of this bottom layer of water further apart, so that it becomes less dense, and consequently *lighter*. The warm water therefore rises to the top, and a colder layer takes its place, to be heated and to rise in its turn. This is called the passage of heat by *convection*. Where hot-water pipes are used, the air of a room is also heated by convection. The molecules of air touching the pipes become heated by their contact with the hot surface of the pipes. They rise, and fresh molecules take their place. This goes on until every molecule of air in the room has in turn been in contact with, and been heated by, the hot pipes.

117. Transmission of Heat by Radiation.—But how is heat transmitted from the Sun to the Earth? The air only extends about two hundred miles above the Earth's surface, and what is there between the Earth and the Sun—which is ninety-three millions of miles away—to carry the heat from the latter to the former? We believe that all the space between the Earth and the Sun and stars is filled with a substance called *ether*. We cannot *prove* the existence of this ether, but we are obliged to conceive of such a substance as existing. The Sun is immensely hot, much hotter than molten iron. The vibrations of the molecules of the hot matter of which the Sun is composed produce *waves* in the ether surrounding the Sun, and these waves of heat spread out in every direction, just as waves do when we throw a stone into the middle of a pond. These heat-waves travel all the way from the Sun to the Earth; and when they strike on the Earth, the motion of the ether is changed into motion of the molecules of the matter on which the heat-waves fall. This is called the passage of heat by *radiation.* All hot bodies radiate or shoot out heat in this way. When we hold our hands in front of a bright fire, it is the heat-waves which the fire is raying out, or radiating, that fall on our skin and produce a sensation of warmth.

We see, then, that there are three ways in which heat can be transmitted:—1. By conduction; 2. By convection; and 3. By radiation.

XX.—HEAT AS A FORM OF ENERGY.

118. Heat produced by Friction—119. How to reduce the Heat produced by Friction—120. Heat produced by Mechanical Energy—121. The Mechanical Equivalent of Heat—122. Conversion of Heat into Mechanical Energy—123. The Steam-Engine.

118. Heat produced by Friction.—Almost every one is in the habit, at some time or other, of rubbing his hands together in order to warm them. This is an excellent instance of heat being produced by friction. The human skin is not perfectly smooth, and when one hand is rubbed against the other, the rough places catch one against the other, and the motion of the hands is more or less stopped.

What becomes of this arrested motion? We have learned that it is converted into heat. Motion of the two hands, as a whole, is changed into motion of the molecules of the skin, and this molecular motion produces in us the sensation of heat. As an experiment, let us fix a bright metal button in a cork, so that we can grasp it easily, and rub the button smartly on a piece of wood. The button will soon become so hot as to burn the skin, to set fire to a piece of phosphorus, or even to a lucifer match. The friction produced when a brake is applied sharply to the wheel of a waggon or an engine is often so great as to produce a stream of sparks. In striking a match we have another example of the heat produced by friction. All common matches have a little phosphorus on them, and the heat produced by the friction of the match on the rough box is sufficient to cause the phosphorus to catch fire.

FIG. 39.—Indian mode of obtaining a light by the friction of one piece of wood against another.

Many Indians obtain fire by the friction of a hard, dry, pointed piece of wood against another piece. Shooting stars or meteors are masses of stone or iron travelling through the air with such a great velocity (forty to sixty miles a second) that their friction *against the air* sets them on fire. Very often friction produces heat where it is not wanted. In this way the axles of railway carriages sometimes become so heated as to set fire to the wood-work of the train; and by friction a workman's tools are often made too hot to be handled.

119. How to reduce the Heat produced by Friction.— In such cases the remedy is to apply oil, or grease, or blacklead, or some other *lubricant* which will fill up the rough places and make the one surface glide more smoothly over the other. The friction will then be less, and less heat will consequently be produced.

120. Heat produced by Mechanical Energy. — By mechanical energy we mean the energy possessed by a body which is moving as a whole. It may be said that this is the same as *kinetic* energy, but the latter term includes molecular motion *as well as* motion of the body as a whole. Thus a red-hot ball hanging by a chain has kinetic energy, because its molecules are in motion; but it has no mechanical energy, for as a ball it is at rest. By means of our muscular force, and the force of gravity, we can set a hammer-head in motion, and impart to it much mechanical energy. By a few smart blows with a hammer an iron nail may be made so hot as to ignite a match, and it is said that a clever blacksmith can so hammer a nail as to make it red-hot. In that case the mechanical energy possessed by the moving hammer is converted into the molecular energy we call heat. If we pick up a bullet that has just been fired at, and has struck, an iron target, we shall find the lead so hot that we shall quickly drop it. When the bullet was moving through the air it had great mechanical energy. When it struck the target its energy was not lost, but it was converted into the kind of molecular energy called heat.

121. The Mechanical Equivalent of Heat.—We can now explain what becomes of the energy of falling bodies. When a stone, or a ball, or a meteor strikes the ground, its mechanical energy may appear to be lost, but it is really *changed* into heat-energy. Both the moving body and the spot on which it struck will be a little warmer after the collision than before. If we require to know *how much* mechanical energy is equal to a given amount of heat, the best answer is to state from what height a pound-weight would have to fall in order to raise one pound of water through one degree Fahrenheit. A great many careful experiments, more especially those made by Dr. Joule of Manchester, have shown that this height is seven hundred and seventy-two feet. If we could take a one-pound weight up in a balloon to a height of seven hundred and seventy-two feet, and let it fall from thence into a basin containing one pound of water at, say, sixty degrees Fahrenheit, and if all the heat produced by the blow went to warm the water, then its temperature after the weight had fallen into it would be exactly sixty-one degrees Fahrenheit. But a weight of one pound falling from a height of seven hundred and seventy-two feet *does seven hundred and seventy-*

two foot-pounds of work. This amount is known as the *mechanical equivalent* of heat.

122. Conversion of Heat into Mechanical Energy.—Suppose that we place some water, at a temperature of, say, 60°, in a kettle on the fire, and keep a thermometer in the water. The temperature of the water steadily rises until it reaches 212°, but at this point it remains constant. Yet heat from the fire is continually passing into the water. What becomes of this heat? Is it lost? Certainly not; it is spent in driving the molecules of water asunder — in overcoming their cohesion—so that the liquid changes into a gas. It is found that water-gas or steam takes up one thousand seven hundred times as much room as the water from which it was derived. One pint of water would produce one thousand seven hundred pints of steam. Heat is the force which has produced motion of the molecules of water, driving them further apart, so that they take up a great deal more room. This is an example of the conversion of heat into mechanical energy.

FIG. 40.
Conversion of liquid water into water-gas, or steam. The molecules of the water are driven asunder by the force of heat.

123. The Steam-Engine.—It is the expansion of water when it is changed from the liquid to the gaseous state that does work in the machine called the steam-engine. The water in the boiler is heated by a fire in the furnace. As the water turns into steam it expands and pushes up a piston. After it has done this, the steam is *condensed*, and the piston falls down again. This up and down motion of the piston is changed by a suitable contrivance into the circular motion of the wheels. Nothing can be clearer than that in a steam-engine we put in heat and take out mechanical energy. Unfortunately we are not able to obtain in this or in any other machine the full *mechanical equivalent* of the heat we employ. A great deal of heat is wasted in warming the different parts of the machine, and much escapes up the chimney. It is certain that the best constructed engines do not give us the mechanical equivalent of more than *one-tenth* of the heat produced by the coal burned in their furnaces.

APPENDIX.

QUESTIONS AND EXERCISES.

I.

1. Name some property by which *matter* can be distinguished from *force*.

2. If there is no force that can directly affect our senses, how do we know that any forces exist?

3. How many kinds of motion are there? Name them. Which kind is recognized by the sense of sight?

II.

4. Name all the forces you know. What one force is very different in its mode of action from all the others?

5. Describe an experiment by which you could produce some of the force called electricity.

6. What do you know about the muscular force?

III.

7. Write out the first law of gravitation. Where could you place a body so that it would not be acted upon by this force?

8. Write out the second law of gravitation. Find the squares of the numbers 1, 32, and 1000.

9. Compare the attraction between two balls, each weighing four pounds, and hanging two feet apart, with that between two balls, each weighing one pound, and hanging one foot apart.

IV.

10. Explain the words *up* and *down*. When a boy in New Zealand throws a ball "up," in what direction is he throwing it compared with a ball thrown "up" by a boy in England?

11. What is meant by the *centre of gravity* of a body? Whereabouts in the body is the centre of gravity of a cricket-ball, a brick, a biscuit, and a slate?

12. Name the three kinds of equilibrium, and give an illustration of each.

V.

13. What did Galileo discover about falling bodies? How and where did he experiment upon them?

14. Describe two experiments by which you can prove that very light bodies fall with the same velocity as heavy ones.

15. Explain the meaning of the word *uniform*. A train passes a station (A) at twelve o'clock, with a velocity of thirty miles an hour; twenty minutes later this train passes a station (B) ten miles off: has its velocity been uniform, or variable? Give a reason for your answer.

VI.

16. State any facts you have noticed which prove that falling bodies move with variable velocity.

17. Explain the words *accelerated*, *retarded*, and *velocity*.

18. A stone dropped into a well is heard to strike the water in four seconds; find (1) the distance from the water to the surface, and (2) the velocity of the stone at the moment it reached the water.

VII.

19. Are the houses which form our streets at rest, or in motion? If they are in motion, how is it that we cannot see them move?

20. Write out the first law of motion. What is another name for this law?

21. Describe any two experiments you would perform to prove that *inertia* is a universal property of matter.

VIII.

22. Explain how it happens that people frequently fall when they step out of a moving train or carriage.

23. Why is it more difficult for a boy to set a loaded truck in motion than for him to keep it in motion after it has once been started?

24. Describe any operations in which the inertia of matter in motion is taken advantage of and utilized.

IX.

25. What effect has friction on a moving body? How can you reduce the friction of any two surfaces?

26. Why does a ball roll to a greater distance on ice than on grass (supposing it to be thrown with the same force in each case)? How far would a ball roll on a perfectly smooth horizontal surface?

27. Point out the advantages and the disadvantages of friction.

X.

28. Explain the words *matter*, *molecule*, *particle*, and *body*.

29. Which will strike the harder blow—a ten pound hammer moving with a velocity of fifteen feet per second, or a twenty-five pound hammer moving six feet per second?

30. State exactly what is meant by the word *mass*. How could we prove that a cubic inch of platinum has twenty-two times the mass of a cubic inch of water?

XI.

31. Three policemen, who can lift separately weights of 290, 310, and 336 pounds, engage in a "tug of war" with three soldiers, whose strength is equal to 300, 306, and 230 pounds respectively. Find which side will win, and draw a diagram representing the six forces in action.

32. Find the resultant of two forces of six pounds and eight pounds respectively, acting parallel to each other on a given point: (1) when the forces act in the *same* direction, (2) when they act in *opposite* directions.

33. Three forces, of six, eight, and ten pounds, act on a given point. What is the greatest resultant they can have, and what is the least?

XII.

34. Write out the second law of motion, and give three examples of its action.

35. Why is it impossible for a soldier in a moving train to hit any object at which he may fire, provided that he aims straight at it?

36. Show how to find the resultant of forces acting in opposite directions. Give an example.

XIII.

37. Write out the third law of motion, and give one illustration of it.

38. A man sitting in a boat attempts to make the boat go backwards by pushing the stern with his oar. Why does he fail to move the boat?

39. When a man-of-war is chasing another ship the sailors object to fire the bow-guns. Have they any reason for this? What would be the effect of firing cannon from the stern of the ship?

XIV.

40. A man, weighing 144 lbs., carries a wheel, weighing 50 lbs., to the top of a hill 1000 feet high; how much *work* has he done? Another man, of the same weight, rolls the wheel down again; in doing this how much work has this second man performed?

41. What is the unit by which work is measured? How much water (ten pounds to the gallon) could a steam-engine of ten horse-power raise in ten minutes from the bottom of a well one hundred feet deep?

XV.

42. What kind of energy does each of the following bodies possess?—(1) gunpowder, (2) a lion, (3) a river, (4) a rubbed piece of sealing-wax, (5) a fire, (6) the wind, (7) a lump of coal.

43. What do you mean by *energy?* How can the energy of a steam-engine be measured?

XVI.

44. Explain the word *potential*, and give four examples of bodies possessing potential energy.

45. Point out the advantage of the Sun to the Earth as a source of energy.

46. How could you impart some potential energy to each of the following bodies?—(1) a stone, (2) a cane, (3) a piece of india-rubber, (4) a clock-weight.

XVII.

47. What is the name of the kind of energy possessed by a body in motion? In the case of a stone lodged on a house-top, what becomes of the energy which the stone had while in motion?

48. Which has the greater energy—a body weighing one pound, and moving with a velocity of ten feet per second; or a body weighing two pounds, and moving five feet per second?

49. If a cannon-ball weighs one pound, and moves with a velocity of one thousand feet per second, find the force of the blow which it will strike in foot-pounds.

XVIII.

50. If energy cannot be destroyed, what becomes of it, and where does it go? For example, what becomes of the energy of a falling stone?

51. Give at least three examples of the change of energy from one form into another.

52. A boy weighing fifty pounds seats himself in a basket, and by

means of a rope passed over a pulley raises himself to a height of twenty feet. How much energy has he expended in doing this, and where did it come from? When he lets himself down, what becomes of the energy?

XIX.

53. Explain these words:—*Theory*, *material*, *mechanical*, *expansion*, *transmission*.

54. Why is it impossible that heat can be any kind of *matter?* If it is not matter, what is it?

XX.

55. Describe any experiment by which you can change mechanical energy into heat.

56. What is the mechanical equivalent of heat? From what height would you have to drop a pound of water in order to raise its temperature ten degrees? (You may suppose that all the heat resulting from the fall is communicated to the water.)

57. What is the source of the mechanical energy of a steam-engine? If an engine can raise a million gallons of water per hour from a depth of one hundred feet, find the horse-power of the engine.

THE END.